TRAFFIC FLOW SIMULATION AND ESTIMATION OF ROAD USER COST ON INDIAN ROAD NETWORK

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

By
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to the
DEPARTMENT OF CIVIL ENGINEERING
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SEPTEMBER, 1988

Dedicated
to
My Parents

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CERTIFICATE

This is to certify that the thesis " Traffic Flow Simulation and Estimation of Road User Cost on Indian Road Network " submitted by Shri Anguluri Nageswara Rao in partial fulfilment of the requirements for the award of Master of Technology of the Indian Institute of Technology, Kanpur, is a record of bonafide research work carried out by him under my supervision and guidance. The work embodied in this thesis has not been submitted elsewhere for the award of a degree.

September 23 ,1988

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Nageswara Rao. A.

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LIST OF SYMBOLS AND ABBREVIATIONS

acon	Constant in Median Speed and Roadwidth Relationship
$acon_i$	Constant in Median Speed and Roadwidth Relationship for a Vehicle Type
ADT	Avrage Daily Traffic
bcon	Constant in Median Speed and Horizontal Radius Relationship
$bcon_i$	Constant in Median Speed and Horizontal Radius Relationship for a Vehicle type
BDS	Basic Desired Speed
C	Constant in Median Speed and Speed Limit Relationship
C_1 , C_2	Rolling Resistance Coefficients
CLASS	A Structure Available in SIMULA for Creating Objects
$C_\emptyset$	Air Resistance Coefficient
COM	Basic Desired Crossing Speed
CON	Median Crossing Speed of The Vehicle
CQ	Q Value With Respect Crossing Speed
C_r	Rolling Resistance Coefficient
Deacc	Deceleration in m/s^2
$Deacc_i$	Deceleration in m/s^2 for Vehicle Type i
DV-Unit	Driver Vehicle Unit
F_L	Air Resistance in Newtons
HDM	Highway Design and Maintenance Model
IITK	Indian Institute of Technology, Kanpur
JSP	Jackson's Structure Programming
Lamda	Overtaking Rate for Constrained Vehicles
M	Mass of Vehicle in Kg.

Mu	Mean Platoon Size
Mu_c	Mean Time Headway for Constrained Vehicles
Mu_f	Mean Time Headway for Free Vehicle
NH	National Highway
p - value	Power/mass Ratio in Watts/kg
P_{red}	Reduced Probability of Overtaking in a Platoon
Q	Speed Transformation Coefficient
Q_i	Speed Transformation Coefficient for Vehicle Type i
q_1	Measure of Rotation for Roadwidth
q_2	Measure of Rotation for Horizontal curve
q_3	Measure of Rotation for Speed Limit
R	Radius of Curve in metres
RECST	Subroutine for Traffic Congestion in HDM
RUCS	Road User Cost Study
v	Speed in km/hr
V_1, V_2, V_3	Median Speeds
V_{1i}, V_{2i}, V_{3i}	Median Speeds for Vehicle Type i
V_b	Road Width in Metres
V_m	Median Speed for Road Width 7m.
V_{mi}	Median Speed for Road Width 7m for Vehicle Type i
V_g	Speed Limit
VØM	Median Speed of the Vehicle
VON	Basic Desired Speed of the Vehicle
Z	Ratio of V_g/V_2

ABSTRACT

The main objective of research presented in this thesis is to determine the road user cost for three different road stretches on three different highways which vary widely in the traffic composition and geometrics. Secondly to modify the existing Indo Swedish Traffic Simulation , road submodel and traffic submodel to capture the highly heterogeneous nature of the Indian traffic.

In the first phase the major effort has been made in understanding traffic behaviour in the simulation program as road conditions and traffic compositions vary. In this regard three stretches on NH7, NH15, NH28 were considered to simulate the traffic with the existing road conditions and for the present and future traffic. The road conditions were modified (i.e. narrow road to two lane wide road) and the traffic is simulated on these stretches. The speed flow relations were obtained for each road for both the conditions. The road user cost has been evaluated for each section under both conditions. In the second step the existing traffic simulation model has been modified by considering the 20 different vehicle types. Some of the procedures were modified to represent the flow behaviour effectively. The road submodel has been modified to calculate the median speed and transformation measure (Q value) for each vehicle type. The traffic submodel has been modified to generate 20 different vehicle types.

CHAPTER I

INTRODUCTION

1.1 General

Transportation contributes to the economic, industrial, social and cultural development of any country. Among all modes of transportation, road transport is the most easily accessible mode available to people. The road network could alone serve the remotest villages of the country. Road transport has recorded a phenomenal growth in the wake of all round national development in the country. Hence there is a need for enhancing and upgrading the road network. This causes substantial pressure on the planners. In order to select the most beneficial scheme from among a number of alternatives, it is necessary to have an economic appraisal of various alternatives. Rational decisions will be required before undertaking such improvements. This necessitates the availability of reliable information regarding time delays, fuel consumption, accident rates and cost of maintenance and spare parts. Given the roadway and its geometric features, the above mentioned factors form the function of speed and quality of flow on these highways.

1.2 Indian Road and Traffic Conditions :

Indian roads comprise primarily of single lane, intermediate lane, two lane and four lane divided carriageways. The roads with pavement width of about 3.75m are designated as single lane bi-directional roads, while the roads of 5.5m wide are generally known as intermediate lane roads. 7m wide roads are the two lane

highways. The four lane divided carriageway roads are 14m to 15m in width, provided with median barrier. In general all the roads are provided with earthern shoulders on either side. Sometimes part of the shoulders of the single lane road has been improved with brick paving to increase the effective width of the roads to facilitate the ease of movement on these roads. The brick paving vary in width from about 0.5m to 1.6m. However, their condition is generally poor due to usage by heavy vehicular traffic. Since the strength of the shoulders is much lower, they deteriorate much faster when subjected to wheel loading. Sometimes the difference in levels is as much as 10cm, at the interface between the pavement and the brick shoulders.

The road traffic on Indian roads is highly heterogeneous, being constituted by vehicle types as fast as Maruti cars and as slow as bullock carts. The fast moving vehicles include light motor vehicles, trucks and buses, tractor, trailer combinations and several categories of two wheelers. Amongst the slow moving vehicles, bicycles, cyclerickshaws and animal drawn vehicles (ADV) dominate the scene.

It has been observed that operating speeds of these vehicles are quite low even at low and medium traffic. This may be attributed due to poor surface conditions, road geometrics, overloading of vehicles, vehicle conditions etc. The traffic on some sections of national highways has grown to such an extent that proposals for widening the two lane highways to four lanes are under consideration. The Government policy to develop some locations as industrial areas and the acute traffic congestion

on many links has created the need for the construction of roads with superior facilities such as expressways. In addition to this, there are numerous proposals to widen some of the existing single lane roads to intermediate and two lane highways.

1.3 Need for Investment Planning :

In the above framework there is an urgent need to develop rational tools to evaluate alternative investment programs. The investments on the proposed schemes are of very high magnitude. Budget and resource constraints forces us to closely examine the various costs and benefits associated with the investment programs such as construction costs, maintenance costs, benefits in the terms of user costs. Such a framework would enable the planner to select a project judiciously among the various investment programs under consideration.

1.4 Earlier Work Done in India :

Realizing the need for setting up certain design standards, evaluation of various project schemes and the necessity to create a database on various road conditions, traffic characteristics, a project Road User Cost Study (RUCS) was sponsored by the Government of India and the International Bank for Reconstruction and Development (World Bank). In order to evaluate the alternative investment policies, we study the road user cost which is an important component of the total transportation cost. The road user cost study in India dealt with only this component of the total transportation cost.

Evaluation of traffic flow characteristics can be made in two ways: through analytical studies and simulation modeling. The simulation modeling project was taken up by the Indian Institute of Technology, Kanpur (IITK) in collaboration with the Swedish National Road and Traffic Research Institute (VTI). The study developed simulation models for single lane, intermediate lane, two lane and four lane conditions with extensive calibration and validation. The simulation models developed for the Indian traffic conditions for single lane, intermediate lane, and two lane roads consider the crossing of vehicles in opposite directions. These models were developed with Swedish model (Brodin, Gynnerstedt and Hevander, 1979) as their basis.

1.5 Indo Swedish Traffic Simulation model :

This model is the modified version of the VTI model, originally developed in Sweden, to suit the road and traffic conditions prevailing in the Indian environment. On the basis of its application the model has been divided into two parts. One part gives the speed of the freely moving vehicle along the road **free flow traffic model** and another part showing the interaction between the individual vehicles in the vehicle streams **interaction model**.

1.5.1 Free Flow Traffic Model :

The road stretch is represented in the model as a series of geometrically homogeneous road blocks. Within each block the factors of roadwidth, radius of curvature, speed limits and

gradients are kept constant. Each driver in the traffic simulation model is allotted a speed from the basic desired speed distribution (BDS). A driver unimpeded by traffic interactions chooses to travel at maximum speed on a wide, straight, horizontal road with no speed restriction and this is termed as basic desired speed(BDS).

The block speed in a particular road block is dependent on the median speed of the road block, transformation coefficient(Q value) and BDS of the vehicle. Apart from the block speed, the slope, if any, is also assigned to the block. Each vehicle has also been allotted a power mass (P/m) ratio, as well as air and rolling resistance, which decides the ability to reach or maintain this block speed on the particular slope. If the vehicle has a speed lesser than the block speed, when entering a block, or it cannot maintain its block speed due to the slope, its speed is calculated using Newton's equation for momentum.

The resulting speed is thus determined from a desire ability situation resulting in a speed profile along the road in which corrections have been made to the block speed with regard to P/m ratio of the vehicle to allow for the vertical profile of the road and the air and rolling resistances.

1.5.2 Interaction Model :

The free vehicle model calculates how free vehicle adopts its speed to road width, alignment, gradient and speed limits. The interaction model takes into account the way in which individual vehicles are influenced by surrounding traffic. The

speed of the vehicle in the traffic stream is influenced by the volume composition and speed distribution of the traffic.

In addition to the speed and P/m ratio, each vehicle is allocated a time and road coordinates for starting, a direction of travel and an initial speed. This permits the faster vehicles to catchup with slower vehicles along the road and leads to overtaking or following. The overtaking has been divided into **flying, accelerating** and **passing**. If overtaking starts as soon as one vehicle catches up with another vehicle, **flying** overtaking take place. If overtaking occurs after **following**, an **accelerated overtaking** is carried out. If the road has a wide shoulder overtaking can also takes place by **passing**, which means that the leading vehicle moves with certain probability on to the shoulders. When **following** occurs, the vehicle follows the preceding vehicle with a constant time headway depending on the preceding vehicle type.

In addition to free movement, vehicles meet each other in opposing directions, decelerate to safe crossing speeds and cross each other. Two opposing vehicles are interacting with each other due to the width of the road on single lane and intermediate lane roads. On these roads vehicles have to yield space and slow down and so it is, if two vehicles are trucks which are crossing on a narrow two lane road. Under the Indian conditions it is more important to consider crossing, since speeds are calculated based on roadwidth, shoulder type and its quality and vehicle types involved in crossing.

1.5.3 Program System for Traffic Simulation :

The simulation program comprises the heart of a program system as shown in the Figure 1.1. The simulation model in a model system permits the following:

a) Simulation of the behaviour of free flow traffic in both directions, i.e. vehicle dependence on road attributes, speed limits in force on vehicle attributes, but excluding the interdependence of the vehicles.

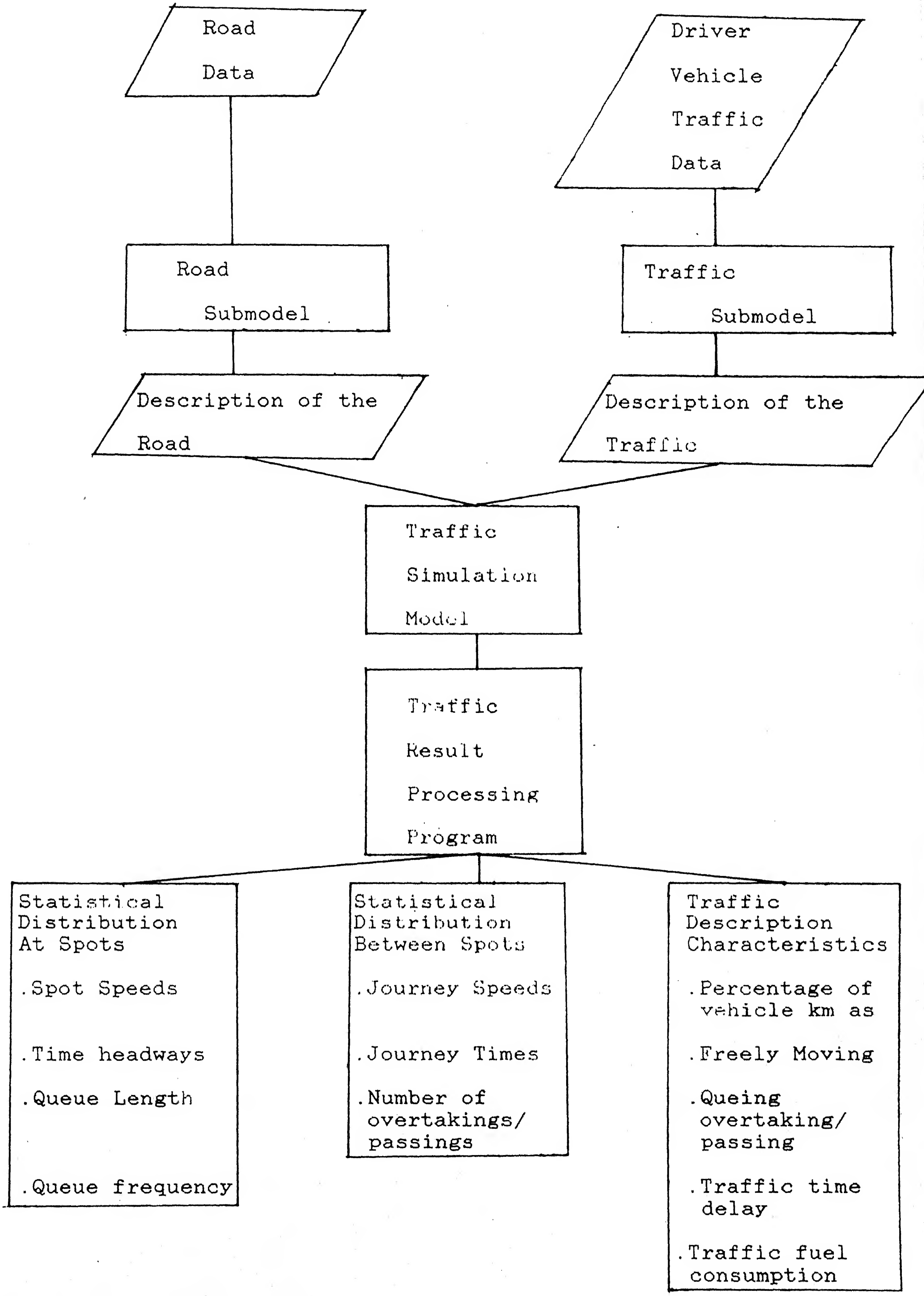
b) Simulation of the behaviour of vehicles also taking into account the interdependence of the surrounding vehicles in their own and the opposite direction.

1.5.4 Road Submodel :

The objective of this model is to represent the road as a series of geometrically homogeneous road blocks and to create a speed profile along the road for each free vehicle. Thus a road block will be of constant road width, curve radius, gradient and speed limit. The speed profile depends on the road geometry and speed limit. The median speed for each block V_3, is a function of the distribution of BDS, road width, horizontal curve, and the speed limit. In addition to that a transformation measure, the Q value for each road block is calculated, which indicates how far the BDS distribution must be rotated about the median speed V_3.

1.5.5 Traffic Submodel :

The traffic submodel describes the traffic characteristics provided as data input to the simulation model. Traffic in the


Road
Data
Driver
Vehicle
Traffic
Data
Road
Submodel
Traffic
Submodel
Description of the
Road
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Traffic
Simulation
Model
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Result
Processing
Program
Statistical
Distribution
At Spots
.Spot Speeds
.Time headways
.Queue Length
.Queue frequency
Statistical
Distribution
Between Spots
.Journey Speeds
.Journey Times
.Number of
overtakings/
passings
Traffic
Description
Characteristics
.Percentage of
vehicle km as
.Freely Moving
.Queing
overtaking/
passing
.Traffic time
delay
.Traffic fuel
consumption

simulation model is represented by number of driver vehicle (DV) units. A DV unit contains the characteristics to model the driver behaviour as well as the vehicle parameters. The traffic is made up of fast as well as slow moving vehicles. Vehicles vary widely in their size, power to mass ratio, operating speed and other characteristics such as vehicle age and condition. Vehicles are classified depending on their size and speed of operation into the four groups.

a) Car.

b) Animal drawn vehicles.

c) Heavy motor vehicles (Trucks and Buses).

d) Light motor vehicles (Motor cycles or scooters).

The attributes of a DV unit are

a) Identification number.

b) Vehicle type.

c) P/m ratio.

d) Basic desired speed.

e) Origin.

f) Destination.

g) Entry time.

h) Entry speed.

Every DV unit in the simulation model is uniquely represented by an index called the identification number. Associated with each DV unit are the vehicle parameters , vehicle type and P/m ratio (p-value). The p-value is a significant factor contributing to the performance capability of the vehicles. Lower p-value limits the ability of a vehicle to climb the grades there

by affecting the capacities of the these road stretches considerably.

1.6 Highway Design and Maintenance Model :

To address the issues concerning highway projects appraisals such as initial construction and maintenance, the World Bank initiated a collaborative research in 1969 involving institutions in several countries to develop a new quantitative basis for decision making the highway sector. In the first phase of the study, completed in 1971, a team at the Massachusetts Institute of Technology, in conjunction with the British Transport and Road Research Laboratory, the French Laboratoire Centrale Despouts et Chausses, and the World Bank, developed a conceptual framework and a first prototype model for interrelating the life cycle costs of highway construction, maintenance and vehicle operation (Moavenzadeh, et al. 1971). Subsequent phases of research have been concentrated on empirical quantification involving field collection of new primary data on the underlying physical and economical relationships and validation of the theoretical model. Four such studies have been carried out in Kenya, the Carribean, India and Brazil.

1.6.1 Description of the model :

The broad concept of the HDM model, is as shown in the figure 1.2. The three interacting sets of cost relationships are added together over time in discounted present values, where costs are determined by predicting physical quantities of

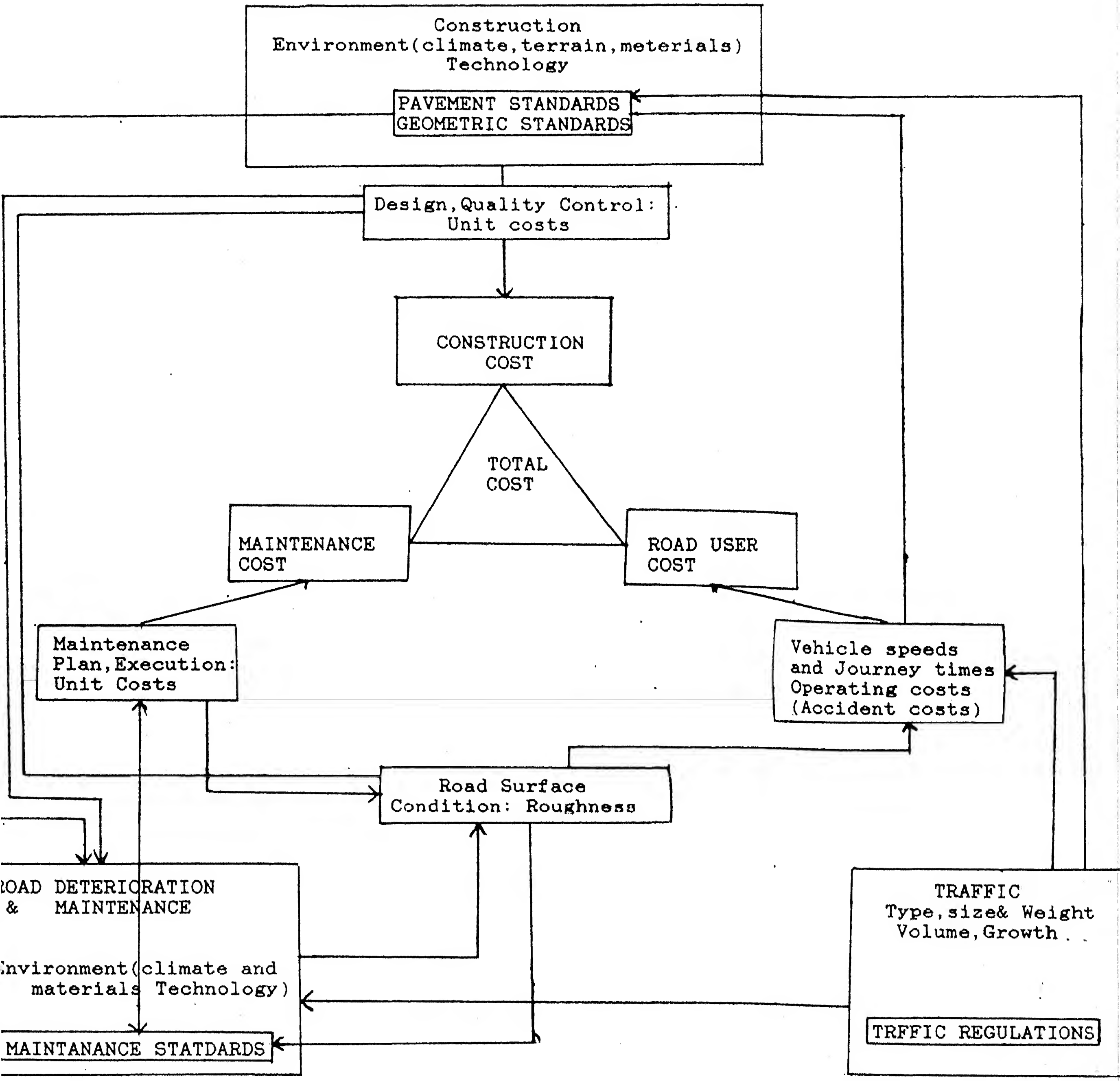


Figure 1.2 INTERACTIOS OF THE COSTS OF ROAD CONSTRUCTION, MAINTENACE AND USE IN HDM MODEL

resource consumption which are then multiplied by unit costs or prices.

Construction costs =f_1 [terrain, soil, rainfall, geometric design, pavement design, unit cost]

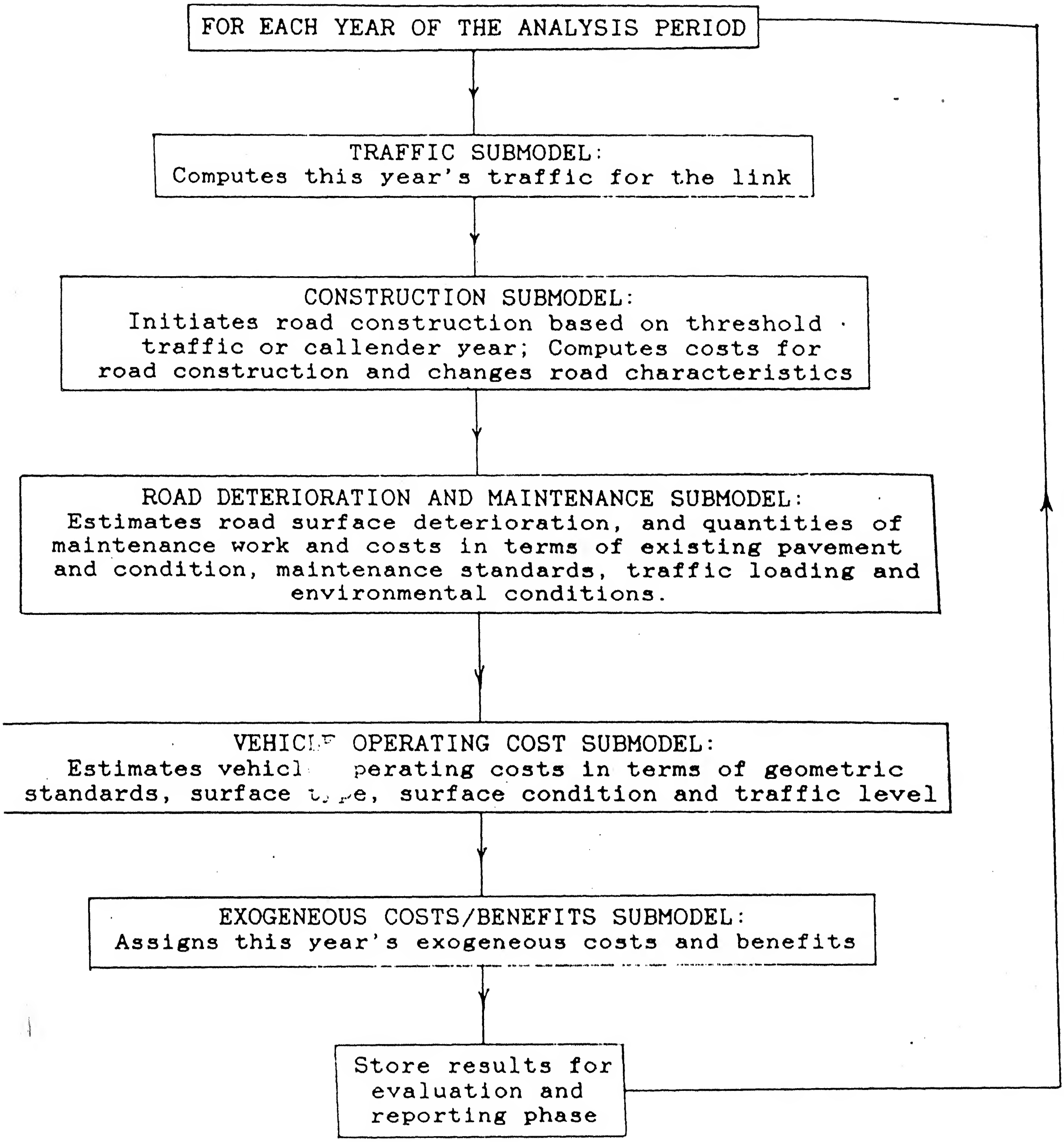
Maintenance cost =f_2 [Road deterioration(pavement design,climate, time, traffic); maintenance standards;unit cost]

Road user cost =f_3 [geometric design; road surface condition; vehicle speed; vehicle type; unit costs.]

Vehicle speed, which is a major determinant of vehicle operating costs, is itself related through a complex set of probability functions to road geometric design, surface condition, vehicle type and driver behavior.

Figure 1.3 shows the sequence of operation of the simulation phase for a given road and associated set of construction and maintenance policies.

The model is used to make comparative cost estimates and economic evaluations of different policy options, including different time staging strategies, either for a given road project on a specific alignment or for group of links on entire network. It can quickly estimate the total costs for large number of alternative project designs and policies year by year for twenty years or more discounting the future costs, if desired at different postulated interest rates so that, the user can search for the alternative with the lowest discounted total or can call for comparisons in terms of rate of return, net present value, or



ig. 1.3 SIMULATION OF A LINK ALTERNATIVE

first year benefit.

1.6.2 Model for Capturing the Effect of Congestion :

The present model calculates the vehicle operating costs under the free flow conditions. Chalapati (1987), has proposed a subroutine (RECST) for congested flow conditions. The basic computational procedure has been modified by dividing the average daily traffic into hourly traffic and the vehicle operating costs are computed for each hour separately. The computational procedure for the routine (RECST) is as follows:

a) The speed volume relationship obtained from the simulation model and the hourly distribution of ADT for each vehicle type should be given as the input to the model. It computes the hourly traffic volume from the hourly distribution of ADT and computes the average journey speed for the volume from the speed flow relationship for each vehicle type.

b) It computes the average journey speed from the multiple regression equations as a function of road geometry.

c) Selects the minimum of the speeds computed from the speed volume relationships and road geometry considerations.

d) Computes the resources used by each vehicle group for paved and unpaved roads.

e) Applies the unit costs to the resources computation to obtain costs per kilometer for each vehicle group for paved and unpaved roads.

f) Computes the cost per vehicle group for each vehicle group from the cost per kilometer.

g) Computes the road user cost for each vehicle group from the cost per vehicle trip for this hourly volume.

h) Adds the road user costs for all 24 hours to obtain the costs for the ADT and computes the road user costs for each group for the given annual traffic volume.

i) It adds all road user costs over all vehicle groups to obtain the total road user costs for the entire analysis year.

Fig. 1.4 illustrates the computational procedure for the congestion model.

1.7 Problem Statement and Objects of Study :

It has been observed that the existing model does not consider the traffic system effectively. In the cars category, many types of cars varying from Maruti to jeeps, which vary widely in their BDS exist. In the trucks category, many types of trucks varying from mini trucks (DCM etc..) to trucks with trailers which vary widely in their BDS and P/m ratio are presently in use. The same is the case with buses and motor cycles also. Hence it is necessary to modify the model to reflect the exact traffic system. In the road submodel median block speed and q value are considered to be the same for all vehicle types. In the simulation model slow moving vehicles are restricted to move with slow speeds, whereas for all other vehicle types median

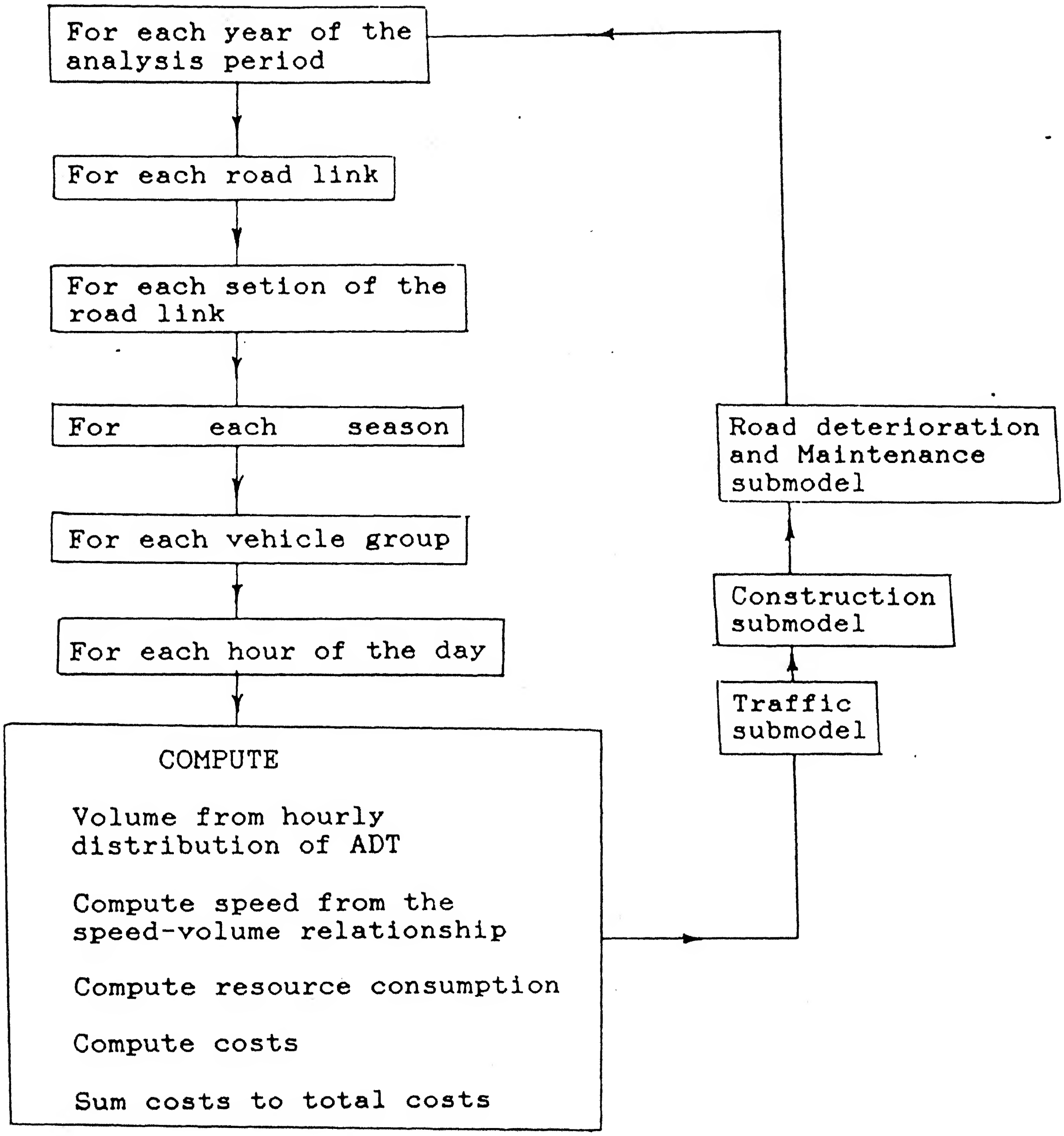


Fig 1.4 RESCST computational procedure

block speed and q value will be the same. Since different vehicle types have different BDS distributions and the variation between the BDS distributions is very high, specifically in the case of Indian traffic, it is necessary to consider the median block speed and Q value separately for each vehicle type. There are many proposals to convert the narrow lane roads to wide roads. Hence it is necessary to study the speed flow relations under narrow and wide road conditions. The road user costs under narrow and wide road conditions as a result of traffic congestion should be evaluated. In this framework it has been decided to modify the existing simulation model and other models, considering the highly heterogeneous traffic conditions that are prevailing on the Indian highways. Finally,the objective is to determine the speed flow relations and road user costs, under narrow and wide road conditions for different roads.

Therefore, the main objective is to modify the existing model to the highly heterogeneous conditions. The second step is to determine the speed flow relations and road user costs for different roads under narrow and wide road conditions.

1.8 Organization of the Thesis :

The thesis is presented in six chapters. Chapter II presents the detailed description of the Indo Swedish Road Traffic simulation model, traffic submodel and road submodel. A brief description of these models and HDM model is presented in this chapter.

Chapter III presents proposed modifications to the

simulation model, road submodel and traffic submodels. The constants assumed for road submodel are also presented.

Chapter IV explains in detail the various inputs and outputs to traffic submodel, validation of the parameters and the experiments with simulation model.

Chapter V explains various experiments carried out on the sections of NH7, NH15 and NH28 under narrow and wide road conditions, determination of speed flow relations and vehicle operating costs.

Chapter VI presents the summary of present work, scope of the study and conclusions drawn from the study.

CHAPTER II

REVIEW OF THE LITERATURE

2.1 GENERAL

The detailed description of the Indo Swedish Traffic Simulation Model for narrow,intermediate and two lane roads is presented in Section 2.2.The traffic behaviour in the simulation models is explained in Section 2.2.2.The various probabilities the model considers for overtaking are explained in Section 2.2.3. The detailed description of road submodel covering from calculation of median speed to the transformation coefficient (Q value) are explained in Section 2.3. The generation of traffic from the calibrated distributions using traffic submodel is presented in Section 2.4.

2.2 Indo Swedish Traffic Simulation Model :

A stochastic discrete event simulation model was developed by the VTI for the two lane bi-directional traffic system during the period 1965 to 1977.It has a long history of calibration and validation over a number of road stretches in Sweden. Subsequently, the model has been used for traffic analysis in providing auxiliary lanes in Finland and the United Kingdom. While RUCS study was initiated in India, the need to develop a simulation model for the Indian road and traffic conditions was felt. Accordingly, an evaluation of several models existing before 1980 led to the conclusion that the best available and reliable model was the one developed by VTI. This model was formed the basis for work done in subsequent years at the Indian Institute of Technology,Kanpur in collaboration with

the scientists of VTI. The version of the model is currently known as the Indo Swedish Traffic Simulation Model(Marwah,1983, Palaniswamy,1983 and Brodin and Palaniswamy,1985).

The traffic and road conditions prevailing in India were too complex to model by simple approaches. It was necessary to incorporate the heterogeneity of traffic and the hosts of road widths along with the shoulders. The basic structure of the VTI model was such that it had built in features that allowed the restructuring of the model for Indian conditions (Gynnerstedt,1983). The program and data structures are based on the Jackson Structured Programming(JSP) technique and has been programmed in one of the highest level of simulation languages - SIMULA 67. The main program principle of SIMULA is pseudo - parallel execution which can be regarded as a further development of event control of dynamic sequences. The model was calibrated and validated extensively for the single, intermediate, and two lane roads.

2.2.1 General Program Design :

The program mainly consists of two processes,which also contain the data and procedures. The are

1. Process class generator process
2. Process class vehicle

The vehicle generator process creates the road objects and allots the individual driver-vehicle attributes. Here they are also allotted their traffic attributes. Parameters which define the vehicle are identity number, basic desired speed and power

mass ratio. Parameters giving their traffic attributes are origin of the vehicle ,destination of the vehicle and entry time. The vehicle generator process also activates vehicles at their starting times.

The vehicle process describes all possibilities for action that a particular vehicle can have,for example "**drive as freely moving vehicle** ","**follow another vehicle**","**overtake the vehicle in front**" ,"**change to another track**" etc. The freedom of choice covers many alternatives the vehicle can have,and the actions are assumed to occur momentarily at calculated times. At each event the model data is updated and a particular event generated from among the possible consecutive event types. A note of the predicted event is inserted chronologically and logically in a list and the events are then executed in this order.

The ordinary cycle for an orbitary vehicle is :

1. Predict the time of the next event - **PRDICTNEXTEVTIME**
2. Wait for the predicted time - **HOLD**
3. Move the vehicle in time and space - **DRIVE**

During the phase 1 of the cycle PREDICTNEXTEVTIME, PREDBLBORDERTIME, AVERSP and PREDICTBLBORDERSP are calculated in their corresponding procedures. During the phase 3 of the cycle the procedure **DRIVE** updates the attributes LOCALTIME, LOCALCOORD, AVERSP, PREDBLBORDERTIME and PREDECTBLBORDERSP.

During the phase 2 of the cycle it may happen that adjacent

vehicle interacts with the current vehicle with the result the predicted time of the next event for this vehicle is shown incorrect, since it will occur earlier. Its ordinary cycle consequently interrupted then the current vehicle considers that a surprise has occurred through the **SURPRISE** procedure. A prediction of new earlier event for the vehicle is then made.

In the program the stretch of the road consists of a sequence of consecutive road block objects and a sight distance function in each direction of travel. Each road block object is homogeneous with regard to the roadwidth,slope,horizontal curvature,roughness,speed limit and overtaking restriction. The road block is represented in the program as an object from the Link class Roadblock. The object has the following important attributes:

.RCO	coordinate of the roadblock
.RBLLENGTH	road block length
.ROADWIDTH	road width class
.LANE	occurrence of auxiliary lane/lateral space
.RI	slope
.RCURVE	radius of curvature
.ROUGHNESS	roughness of the road
.RQ	Q value with respect to normal speed
.IR	block median speed
.DVQ	IR^{RQ} - (median speed of the vehicle)^{RQ}
.CR	block cross median speed
.CQ	Q value with respect to crossing speed
.CVQ	CR^{CQ}-(median crossing speed of the vehicle)^{CQ}

CQ, CVQ and CR are considered for accounting the traffic behaviour on narrow roads.

2.2.2 Representation of Traffic Behaviour :

Figure 2.1 shows the representation of lanes across the road width. A vehicle unimpeded by other traffic normally chooses to travel in lane 2. Thus lane 2 is used when driving under normal conditions whereas lane3 is used while yielding to a faster vehicle from behind, and lane 1 is used while overtaking a slow vehicle. When vehicle ,P,is caught up behind by a faster vehicle, Q,in lane 2 then P would move on to lane 3 with certain probability so that, the catching up vehicle could pass P in lane 2 (Fig 2.2)

When the catching up vehicle Q is not allowed to pass in its normal lane ,i.e. when shoulder is not present,or when P rejects to move on to the shoulder , Q would look for a gap in lane 1 and starts overtaking without having to reduce its speed. This is termed as "flying overtaking". Figure 2.3 shows the steps involved in flying overtaking. When the gap available in lane 1 is not acceptable by the caught up vehicle Q,then it prepares to follow P at a safe distance. When an opportunity to overtake is accepted then Q moves on to lane 1 for an accelerated overtaking. Thus,lane 1 is normally used for overtaking maneuvers,lane 2 when unconstrained by other traffic or while following a vehicle in front ,and lane 3 to allow a faster vehicle caught from behind to pass in lane 2.This logic with some modifications has been applied for single lane,intermediate lane

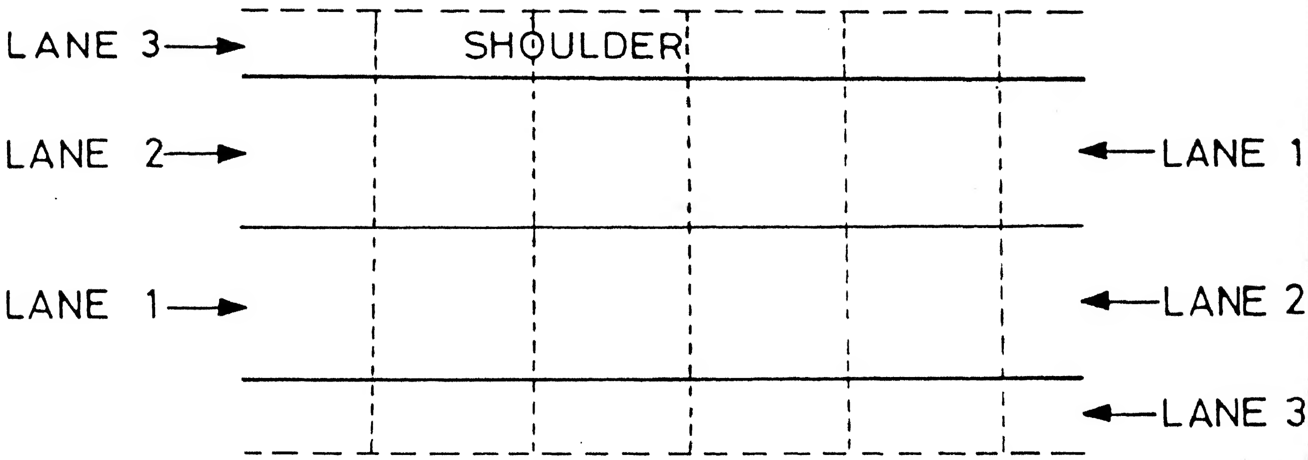
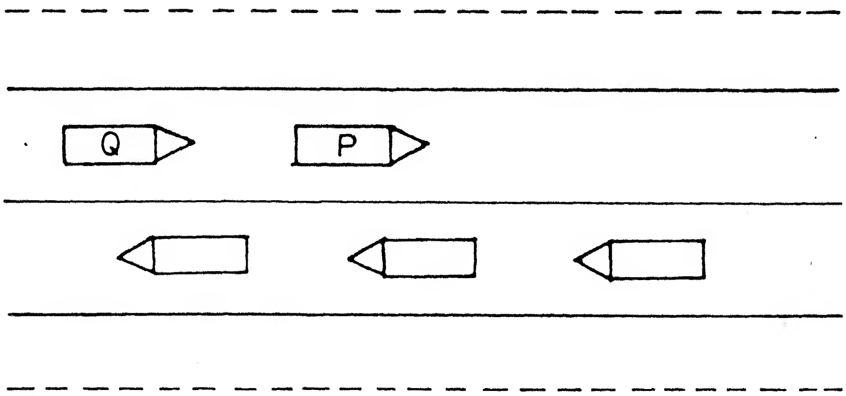
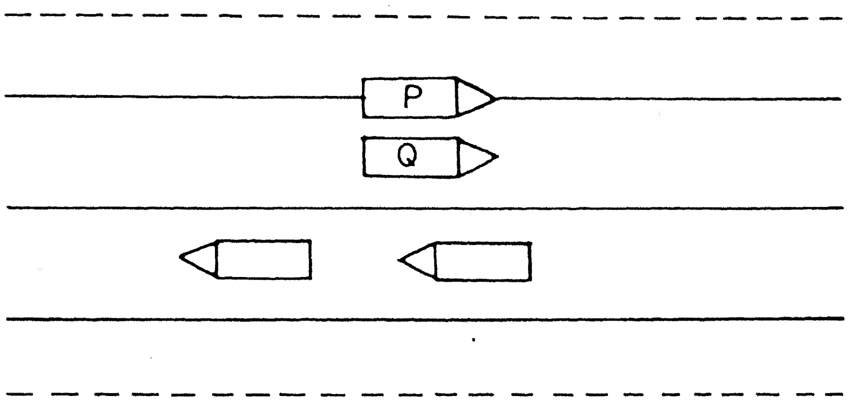


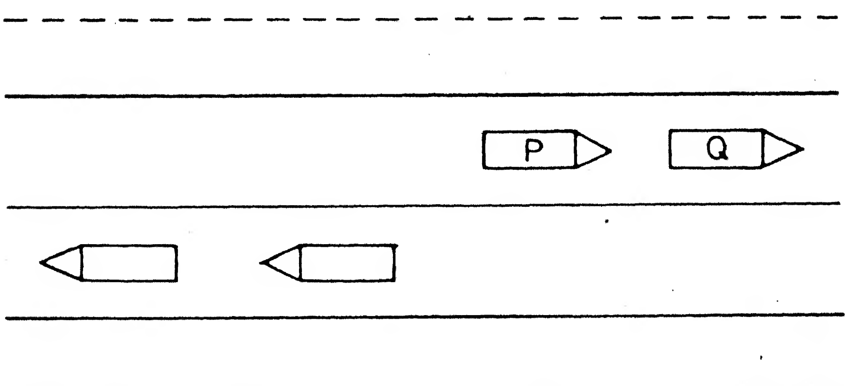
FIG. 2.1 REPRESENTATION OF ROAD IN INDO-SWEDISH TRAFFIC SIMULATION MODELS



(a) VEHICLE Q CATCHINGUP WITH P

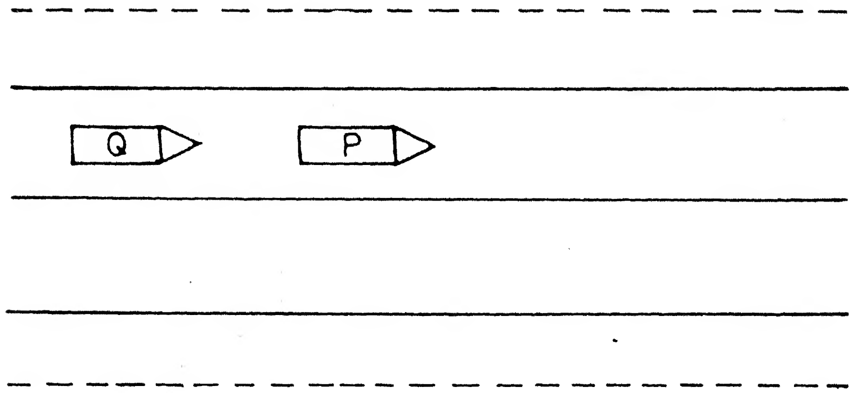


(b) Q PASSING P

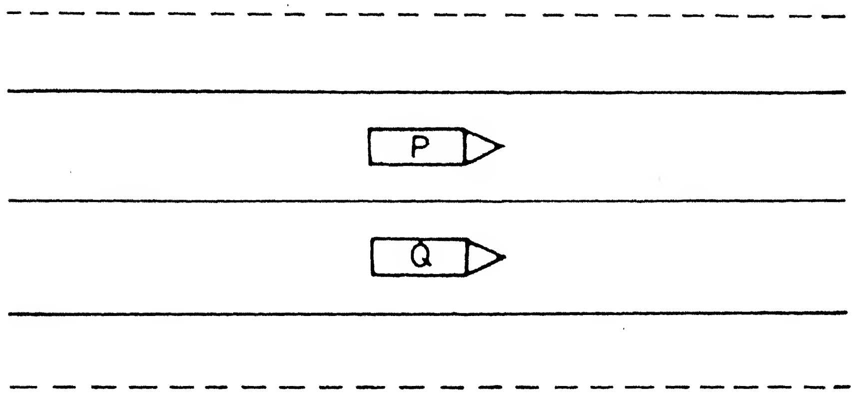


(c) PASSING COMPLETED

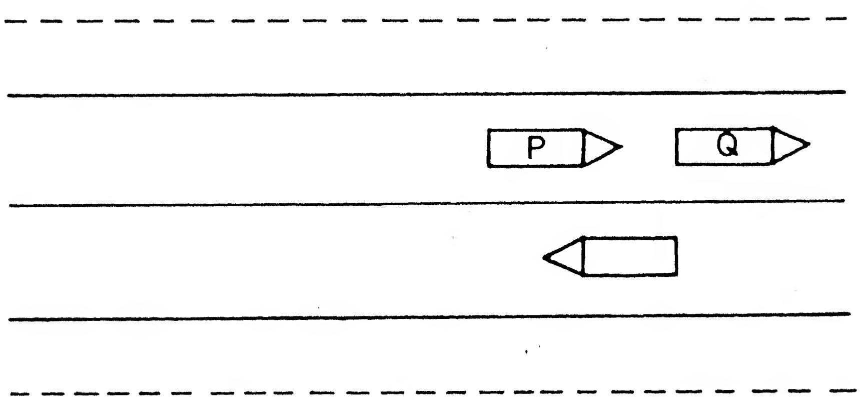
FIG. 2.2 PASSING MANOEUVRE DESCRIBED IN INDO SWEDISH TRAFFIC SIMULATION MODELS



(a) VEHICLE Q CATCHINGUP WITH P



(b) Q FLY OVERTAKING P IN LANE 1



(c) FLYING OVERTAKING COMPLETED

IG.2.3 FLYING OVERTAKING PROCEDURE DESCRIBED IN INDO-SWEDISH TRAFFIC SIMULATION MODELS

and two lane bi-directional movement conditions.

Each vehicle has been allotted a "head" and a "tail". The driving rule in these models tries to maintain a minimum gap between any two vehicles, in the same lane. In order to ensure that this gap is maintained, the head length and tail length are defined for each as follows.

$$\text{Headlength} = \frac{(V_{forward} - V_{follow})^2}{2*Deacc} \quad \text{if } V_{forward} < V_{follow}$$

$$= \emptyset \text{ otherwise.}$$

$$\text{Taillength} = Th_{follow} * V_{follow}$$

where $V_{forward}$ is average speed of the preceding vehicle.

V_{follow} is average speed of the following vehicle.

Th_{follow} is the time headway of the following vehicle.

Deacc is the retardation rate.

Head length therefore indicates the distance required to slow down with the given retardation to the speed of the preceding vehicle. The tail length is chosen so that vehicles in queue are separated by given time intervals.

As shown in Figure 2.1 roadwidth is divided into homogeneous blocks. Each block has a median speed IR, Q value and RQ in addition to other attributes. In the case of narrow roads median cross velocity(CR), Q value for cross velocity and CVQ for each block are also present. the DVQ and CVQ are calculated as explained in the Section 2.2.1.

When a vehicle enters a block its free block speed and in

the case of narrow roads free block and its free cross speeds are calculated by using the following formulae.

Free block speed = $(VØN^{Q} + DVQ)^{1/RQ}$

Frees cross speed = $(CON^{CQ} + CVQ)^{1/CQ}$

A numerical integration of the power equation over time is applied to determine the speed and time of reaching the block border. The procedure continues till the free block speed has been exceeded or the block border has been reached (Fig 2.4).

v is the current speed of the vehicle

$a = dv/dt$ gives $v_t = v_{t-\Delta t} + \Delta t * a$

$v = ds/dt$ gives $s_t = s_{t-\Delta t} + \Delta t*(v_t + v_{t-\Delta t})/2$

where a = acceleration

v = speed

s = distance

t = time

Integration step Delta t is set to

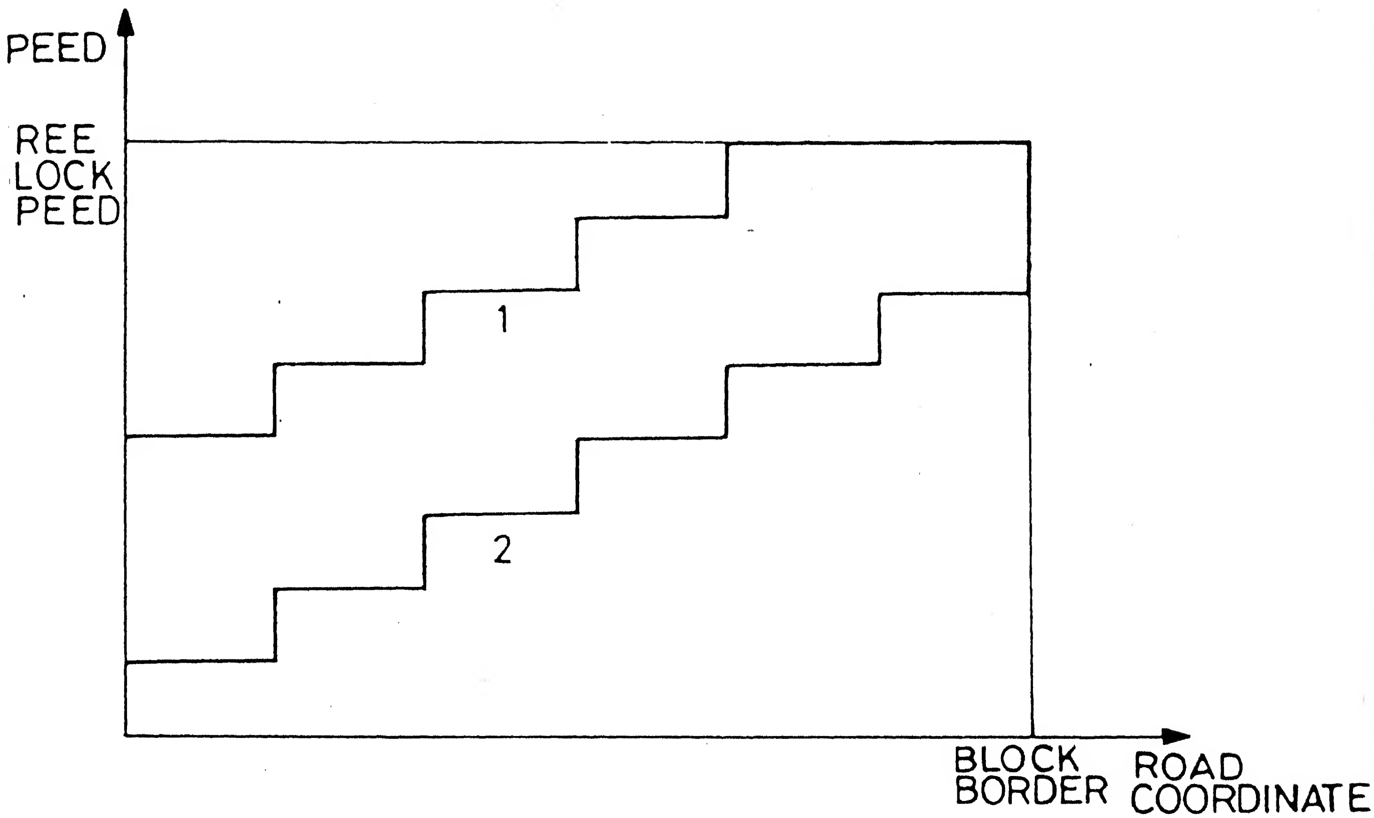
max(6Ø-Vø*3,3)*Precision*Abs(vø/aø)

Precision is the required precision in integration.

In the program precision has been set to Ø.5 percent. vø and aø are speed and the acceleration at the begining. The proposed modifications are explained in Chapter III.

2.2.3 Probabilities of overtaking :

The driver's desire to perform an overtaking operation with a given free sight distance is determined in the model by set



G. 24 NUMERICAL INTEGRATION OF POWER EQUATION TO OBTAIN TIME OF REACHING THE BLOCK BORDER AND SPEED FOR A FREE MOVING VEHICLE

of stochastic functions. The probability of accepting a free sight distance of a given length when opportunity for overtaking is offered, depends on different overtaking situations as described below:

Type of overtaking	1. flying
	2. accelerating
Sight limitation	1. oncoming vehicle
	2. natural obstruction
Overtaken vehicle	1. vehicle type 1, speed < 90 km/h
	2. vehicle type 1, speed > 90 km/h
	3. vehicle type 2, speed < 90 km/h
	4. vehicle type 2, speed > 90 km/h
	5. vehicle type 3 or 4
Road width	1. hard shoulder > 2m, corresponding to a paved roadwidth of 11m.
	2. others

The probabilities are given by

$$p(x) \begin{cases} = \emptyset & \text{if } x \leq S1\text{m.} \\ = a(x-S1)/(S2-S1) & \text{if } S1 < x < S2\text{m.} \\ = \cancel{\text{others}}\ a & \text{if } S2 \leq x \text{ m.} \end{cases} \qquad (2.1)$$

where x is a free sight distance and a,S1,S2 are calibration constants.

In addition, if the vehicle is in platoon, the probability is reduced as follows:

$P_{red} = p*k^{(\text{place in platoon} - 1)}$.

where P_{red} is the reduced probability.

p is obtained from the equation 2.1.

k is the model constant at present it is set to Ø.75.

This procedure is modified to more simpler form and is

explained in the next Chapter.

2.3 Road Submodel :

This model creates the road as a series of homogeneous road blocks and the variation of sight distance along the road, as input to the simulation program. In the simulation model each element has an essential characteristic, its BDS. This is the speed at which the driver would choose to travel on a wide,straight horizontal road with no speed limit,i.e."free speed". Brodin and Carlsson(1983) described free speed as a function of road geometry and BDS, which formed the basis for the for VTI model(Brodin,1983) and Indo Swedish Traffic Simulation Models(CRRI,(a) and (b), 1985,and Brodin and Palaniswamy, 1985). The road submodel described by Brodin and Carlsson(1983) is explained in this Chapter. This is modified to a more general form and is explained in the next Chapter.

It is assumed that for a straight horizontal road having width of 12m or more,there is BDS distribution and from that vehicle chooses to travel at a speed known as its BDS. The vehicle is prevented from maintaining its BDS by the following factors.

.a road width less than 12m.

.curves with a radius of less than 1000m.

.speed limits.

.upward gradients.

Effect of roadwidth :

For a road width under 12m, the median basic desired speed V_0 is reduced to a median speed V_1. It is assumed that roads with over 7m paved are built with a carriage way 7m wide, the remaining width consisting of two hard shoulders. For a road width less than 7m it is assumed that no hard shoulders are provided.

The median speed V_1 is given by :

$$\frac{1}{V_1} = \frac{1}{V_m} + \frac{acon}{V_b - 2.5} - \frac{acon}{4.5}$$

where V_b is the road width in m.

acon is the calibration constant with a value of 0.042.

V_m is the median speed for 7m road width.

Figure 2.5 shows the variation of V_1 for a =0.041, 0.056 and 0.028

Effect of horizontal curves:

If the road includes a horizontal curve ,the median speed V_1 must be reduced taking into account the horizontal radius. Curves with a mean radius $r > 1000$m do not affect the speed V_1. If $r \leq 1000$m the median speed V_2 on the curve is obtained by the following expression, where speeds V_2 and V_1 are given in m/s.

$$V_2 = \frac{1}{\mathrm{SQRT}((1/V_1)^2 + bcon(1/r - 0.001))}$$

where r is the mean radius in m.

bcon is the calibration constant with a value 0.15.

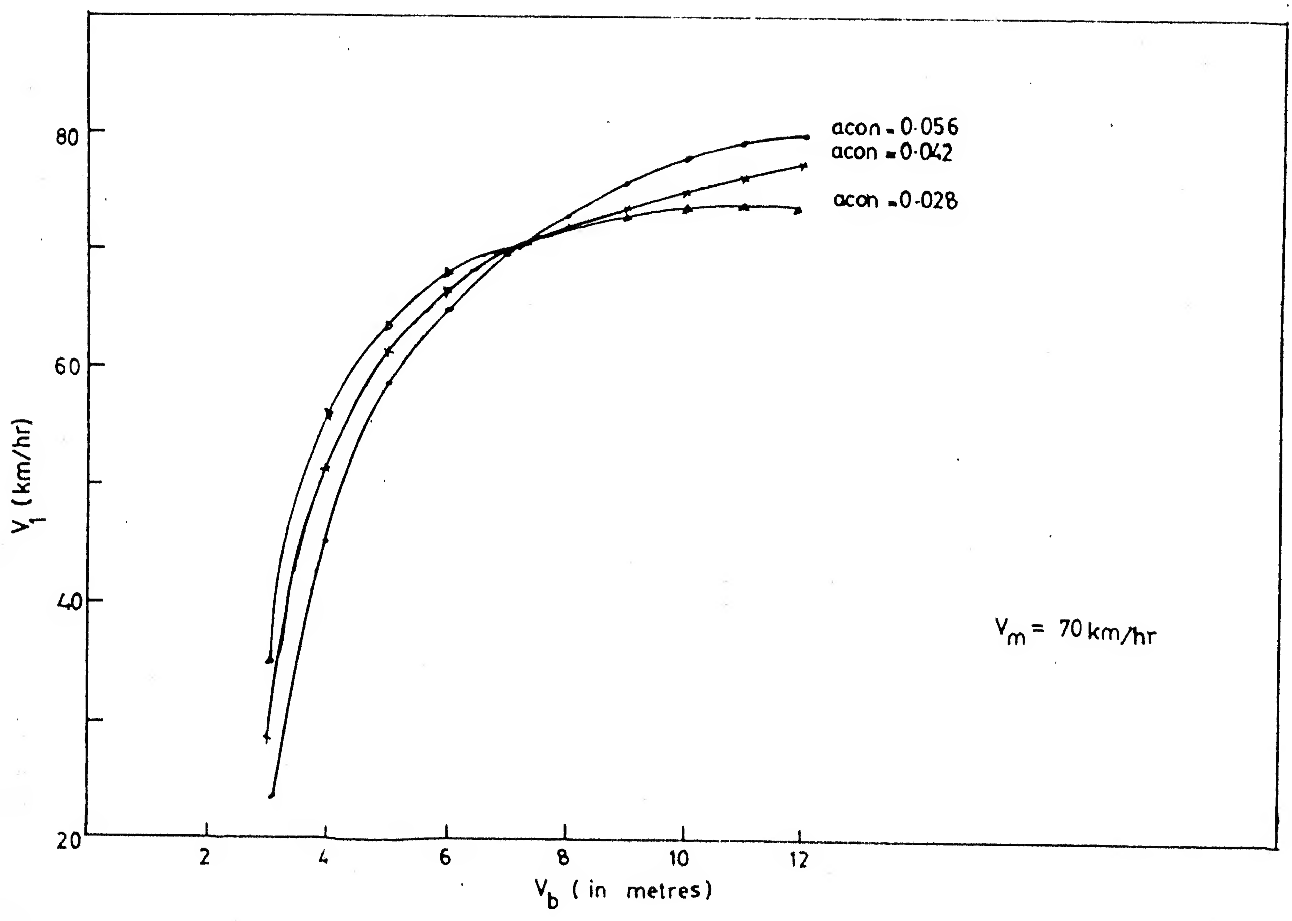


FIG. 2.5 MEDIAN SPEED V_1 Vs ROADWIDTH V_b

V_1 is the median speed on straight road.

From the equation it is observed that, the entry speed V_1 mainly influences the speed V_2 in large radius curves. for small radius curves constant bcon has the greatest effect. Figure 2.6 shows variation of V_2.

Effect of speed limit:

For a speed limit, the median speed V_3 is obtained with the following expression.

$$V_3 = \frac{V_2}{1 + c*dz^2}$$

z is the ratio of the speed limit V_g to the free speed V_2. i.e. $z = V_g/V_2$.

c and d are the calibration constants.

d has the value 0.082, while c depends on the speed limit.

$c = 0.85$ if $V_g < 105$ km/h

$= 1.35$ if $V_g \geq 105$ km/h

After the median speed, V_3 has been calculated, the resulting distribution V_3 must be determined. A transformation measure, Q, indicates as to how far the basic desired speed distribution must be rotated about the median speed V_3. The Q value is a function of the median speeds $V_0, V_1, V_2,$ and V_3. The free speed distribution V_3, using the Q value transformation is determined as follows:

$$V^Q_{0i} - V^Q_{3i} = V^Q_0 - V^Q_3$$

Where V_{0i} and V_{3i} are speeds at an arbitrary percentile in

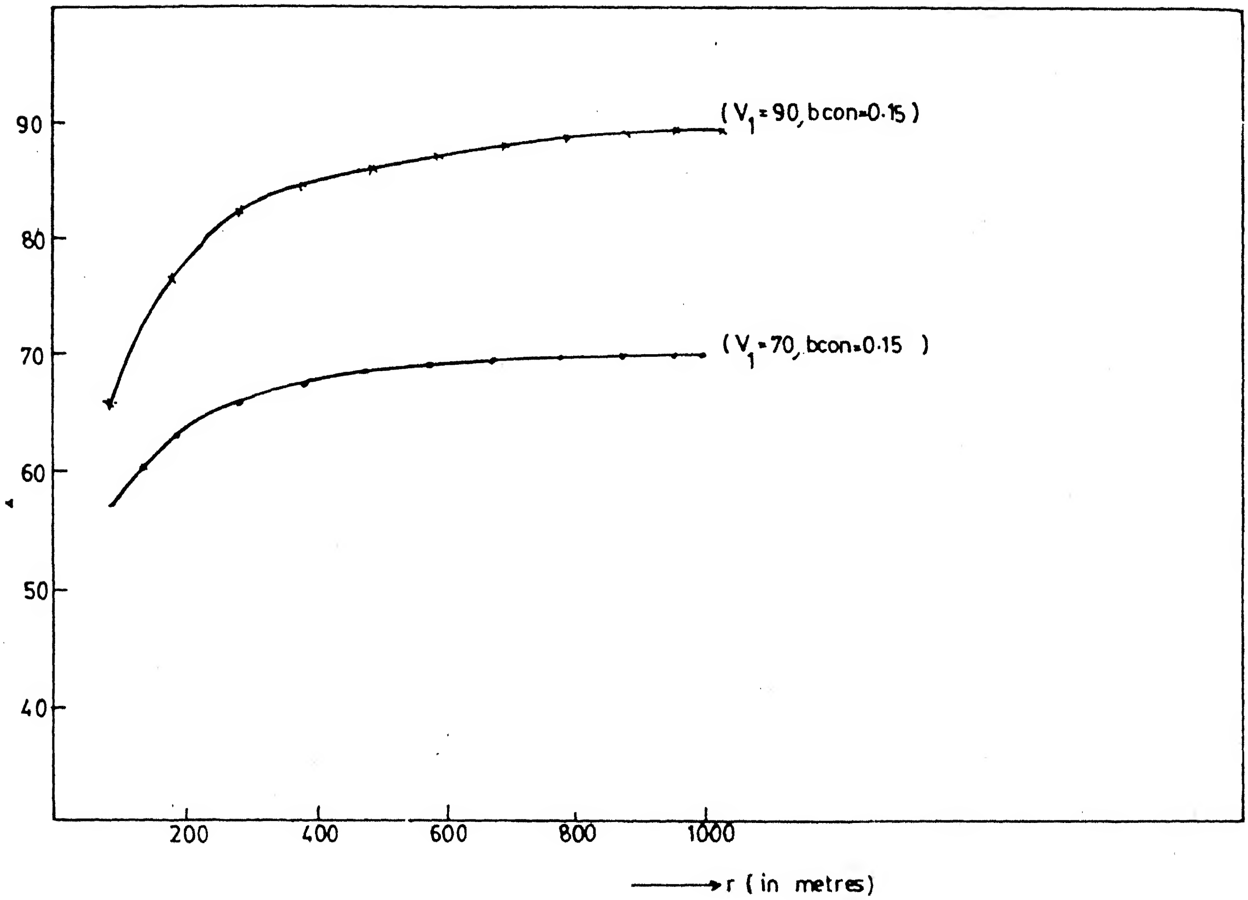


FIG. 2.6 MEDIAN SPEED V_2 Vs RADIUS OF CURVE r

basic desired speed and free speed distributions respectively.

If $Q = 1$ then the above equation results in a purely parallel shift indicating a constant reduction in speed for fast moving as well as slow moving vehicles.

However, when $Q < 1$ the free speed distribution, V_3, is rotated in anticlockwise direction showing that a driver with a higher BDS reduces his speed more than a driver with a lower BDS when influenced by speed reducing factors(Fig 2.7). It must be noted that the smaller the value of Q, the larger will be the rotation.

Each of the factors of the road width, horizontal curve and speed limit has its own isolated measure of rotation, termed q.

These factors are:

$q_1 = 0.5$ for road width

$q_2 = -0.8$ for horizontal curve

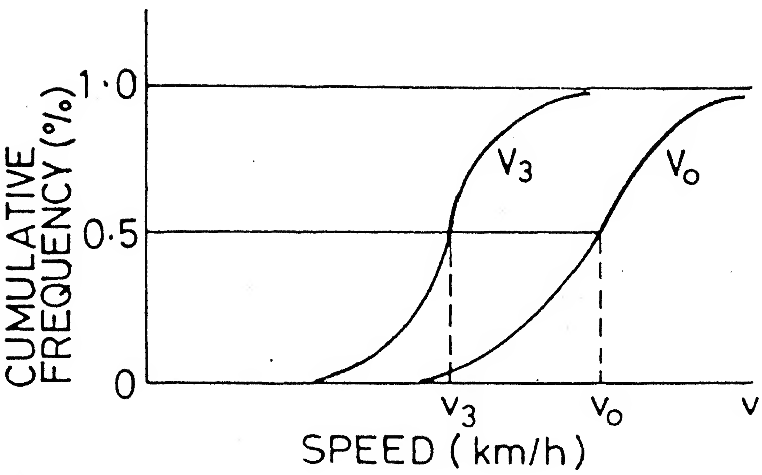
$q_3 = -3.0$ for speed limit

All values of $q_i < 1$. As it has been observed, the value for a speed limit is the smallest and therefore has the greatest effect upon the rotation.

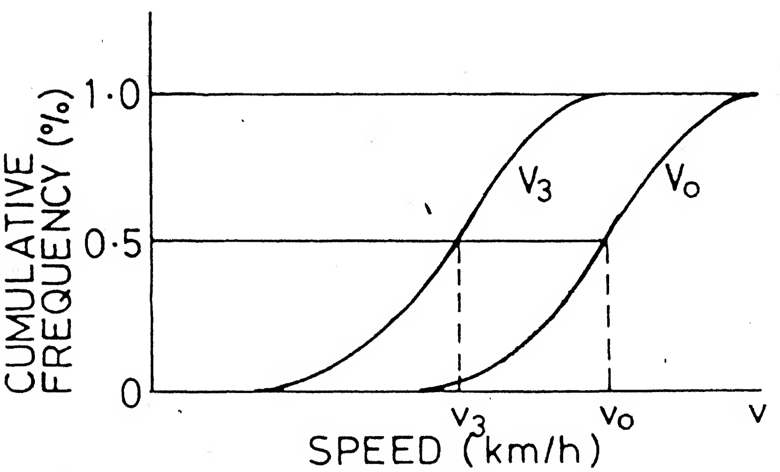
The total measure of transformation Q is function of q_i with median speed V_1, V_2 and V_3 included as weighing factors.

$$Q = \frac{q_1 * K_1 + q_2 * K_2 + q_3 * K_3}{K_1 + K_2 + K_3}$$

where $K_1 = V_0 - V_1$



EFFECT OF ROAD GEOMETRY ON BDS DISTRIBUTION V_o



'IG.2.7 EFFECT OF ROAD GEOMETRY ON BDS DISTRIBUTION; UNIFORM REDUCTION AT HIGH AS WELL AS LOW SPEEDS

$$K_2 = 2(V_1 - V_2)$$

$$K_3 = 2.5(V_2 - V_3)$$

Hence Q is the weighted mean of q_1, q_2, q_3.

2.4 Traffic Submodel :

This model assigns the vehicle characteristics (identity number, basic desired speed and P/m ratio) as well as traffic characteristics (starting point ,starting time and destination). This model was originally developed by Clive Gilliams of U.K.department of Transport. The current model is the modified version. The distribution of vehicles among the four classes (i.e. cars, trucks,ADV and motor cycles/scooters) is to be specified in the input data. The procedure for generating the vehicle as well as traffic parameters is explained below.

Identification Number: This is trivially generated by incrementing each time a vehicle is generated to enter the simulated road stretch at the specified coordinate.

Vehicle type: A distribution of vehicle types is specified for the anticipated traffic composition. The vehicle type of an individual vehicle is obtained from the distribution.

Basic desired speed: The vehicles are uniformly distributed over the basic desired speed distribution for each vehicle type as specified in the input. It generates the BDS from the given distribution. The BDS for ADV is kept between 3.0m/s to 5.0m/s.

Power to mass ratio: The power equation can be obtained as follows.

Consider a vehicle on the upgrade. Figure 2.8 shows the various forces acting on the vehicle. The force equation gives

$ma = F - F_L - F_r - mg*Sin(i)$

where m = mass of the vehicle in kg.

a = acceleration in m/s^2.

F = tractive force in Newtons.

F_L = air resistance in Newtons.

F_r = rolling resistance in Newtons.

g = gravitational acceleration in ms^{-2}.

i = gradient in m/km.

The tractive force at the wheels can be written as $F = P/V$ where P is the power available, measured at the wheels in Watts and V is the speed in ms^{-1}.

The air resistance is expressed as $F_L = C_L AV^2$ where C_L is an air resistance coefficient in kg/m^3 and A is the frontal area in m^2.

The rolling resistance F_r is expressed as

$$F_r = mCos(i)*(C_{r1} + C_{r2}V)$$

$$\approx m(C_{r1} + C_{r2}V)$$

The gravitational force is expressed as $mgSin(i) = mgi$

Substituting the above expressions in force equation, we get

$$ma = P/V - C_L AV^2 - m(C_{cr1} + C_{cr2}) - mgi$$

$$a = \frac{(P/m)}{V} - \frac{C_L A}{m}V^2 - (C_{cr1} + C_{cr2}V) - gi$$

$$\frac{P}{m} = V\frac{dv}{dt} + \frac{C_L AV^3}{m} + C_r V + gv$$

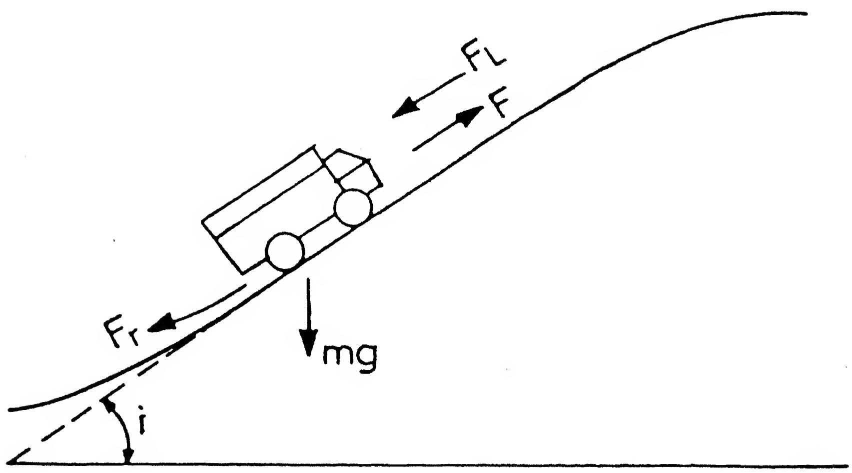


FIG. 2.8 FORCES ACTING ON A VEHICLE ON AN UPGRADE

Integrating the above equation, we get

$$\frac{P}{m} = \frac{1}{t}\int \frac{P}{m}\,dt$$

or

$$\frac{P}{m} = \frac{1}{2}(V_1^2 - V_\varnothing^2) + \frac{C_L A V^2}{m}\int_{S_\varnothing}^{S_1} V^2\,ds + \frac{(S_1 + S_\varnothing)}{t_1} C_{r1} + \frac{gh}{t_1}$$

where left hand side of the equation is the mean power/mass ratio between coordinates $S_\varnothing$ and S_1, t_1 is the mean time taken to travel the distance $(S_1 - S_\varnothing)$.

A p value is sampled randomly from the power mass ratio distribution relevant to the vehicle type. A check is then made as follows: the driver can maintain his basic desired speed on a flat road with this p value. In the equation 2.1, by setting $dv/dt = \varnothing$ and the gradient as zero, we obtain the following equation for the equilibrium speed, V_e, for the vehicle with a p value.

$$\frac{C_L A V_e^3}{m} + C_r V_e - p = \varnothing$$

the equation is solved numerically to obtain the value V_e. If V_e is greater than the desired speed then the condition is satisfied and the vehicle is assigned the p value. Otherwise, new p values are sampled until the condition is satisfied.

In the model the power mass ratio for animal drawn vehicles is kept constant with 1Ø.ØØ. However, the simulation model restricts the speeds of the ADV's between 3.Ø m/s to 5.Ø m/s. Hence the assigned P/m ratio do not comes into the picture for

calculating the freeblock speed etc.

Entry Time : The entry time for each vehicle entering the the simulated road stretch is generated using the Shchul's(1955) composite time headway model. The usual form of the composite distribution is $f(t) = (1 - alpha)*g(t) + alpha*h(t)$

where f(t) is the probability density function of the composite headway distribution, g(t) is the probability density function of the headway distribution for free moving vehicle, h(t) is the probability density function for constrained vehicles, and alpha is the proportion of the constrained vehicles. Branston(1976) who analyzed the constrained time headways on the two lane roads in Indiana, USA, found that a lognormal distribution fitted the data with a mean of 2 seconds and a standard deviation of logarithms of constrained headways $(SIGMA)_c$ of Ø.4. The time headway distribution of free moving vehicles is determined by the platoon length,n. The total headway for a platoon length n is the sum of the one headway for the free moving platoon leader and (n-1) mean headways for the constrained vehicles. the mean time headway for the stream can be expressed as

$$\frac{Mu}{q} = Mu_f + (Mu - 1)*Mu_c$$

where Mu is the mean of the platoon size, q is the traffic flow in veh/h and Mu_f and Mu_c are the mean time headways for free and constrained vehicles respectively. A two parameter distribution due to Miller(1974) has been used for the

generation of platoon size. The distribution of a platoon size r is defined as

$$p_r = \frac{(s + r - 1)}{(m + s + r + 1)} p_{r-1} \quad \text{if } r > 1$$

$$= \frac{(m + 1)}{(m + s + 2)} \quad \text{if } r = 1$$

Miller(1965) found that Mu may be estimated by using the equation

$$Mu_{est} = 0.58 + 1.58*z$$

$$\text{where } z = \frac{0.1 *q}{Lamda(1-q*Mu_c)}$$

where Lamda is the overtaking rate for constrained vehicles. Now, the problem of estimating the Mu is reduced to that of estimating Lamda for a given road traffic flow. Miller(1963) used data collected on a single straight two lane road in Sweden to produce the estimate

$Lamda_{est} = 2750\ Q^{-0.62}$, where Q is the oncoming flow.

Here the oncoming flow is assumed to be the traffic flow given as input,q.

Entry speed : For a free vehicle the entry speed is taken to be equal to 0.85*BDS. In the case of constrained vehicles , the minimum BDS among the platoon is calculated(BDS_{minpl}) and $0.85*BDS_{minpl}$, is assigned as the entry speed of all the vehicles in the platoon. However, all these speeds are constantly reassessed once the vehicle enters the road stretch to be

simulated. Hence the entry speeds assigned are comparatively less important.

Detailed description of the existing traffic simulation model, road submodel and traffic submodel is presented in this Chapter. To capture the highly heterogeneous nature of the Indian traffic, these models are modified. The proposed modifications for road submodel, traffic submodel and simulation model are presented in the next chapter. Chapter IV explains the modified road data structure and vehicle data structure. Various experiments are carried out with modified simulation model. The details of the experiments and the discussion of results are also presented in Chapter IV. Chapter V explains the various experiments carried out on three different Indian roads and the estimation of road user cost. These experiments are carried with the existing models.

CHAPTER III

PROPOSED MODIFICATIONS

3.1 General

As explained in chapter II the traffic simulation model requires extensive data input regarding the road stretch to be simulated, traffic data and model parameters such as passing or overtaking gap acceptance probabilities, time headway for each vehicle type, retardation coefficient etc. As explained in Chapter I the model at present considers four vehicle types. Under the proposed modifications 20 vehicle types are assumed to reflect the heterogeneity prevailing in the traffic system, road data structure is modified by considering the median block speed and Q values for each vehicle type. The proposed modification to the road submodel are explained in section 3.2. The traffic submodel is modified to generate 20 vehicle types. The assumed P/m distributions and BDS are explained in section 3.3. The traffic simulation model has been modified and the proposed modifications are described in section 3.4.

For each vehicle type data such as P/m distribution, BDS distribution are required for the traffic submodel. In the case of road submodel constants such as acon and bcon are needed for each vehicle type under the proposed modifications. Since all the data is not available, values are assumed intuitively with help of the available data. These values are to be evaluated by further effort in data collection and modeling. Once their values are available they can be substituted and the model system can be made versatile .

3.2 Proposed Road Submodel :

It is assumed that the median block speed, V_{3i}, for a particular vehicle type i is dependent on the roadwidth and radius of curvature. The effect of speed limit on V_{3i} is negligible for many vehicle types for example in the case of tractors and slow moving vehicles . Hence the effect is assumed zero for these vehicle types. Since they are already moving with slow speeds, the effect due to speed limit is negligible for all these vehicle types. The transformation measure(Q value) due to road width, horizontal curvature and speed limit is high for the slow moving vehicles showing the minimum effect on rotation. It is general that the effect of road width and curvature on speed is high in the case of fast moving vehicles compared to slow moving vehicles. Since slow moving vehicles are already operating at lower speed, and the reduction is much less due to the effect of roadwidth and curvature. As explained in Chapter II, smaller the Q values larger will be the rotation. Hence in the case of fast moving vehicles generally Q value is less, compared to the slow moving vehicles. Taking these concepts into account the acon and bcon values for each vehicle type are evaluated by experimenting with the help of Lotus 1-2-3 environment.

Effect of road width: For a road width under 12m, the median basic desired speed for a vehicle type V_{0i} is reduced to the median speed V_{1i}. It is assumed as in the original model, roads with 7m paved are built with a carriage way 7m wide, the

remaining width consisting of two hard shoulders. For a road width less than 7m, it is assumed that no hard shoulder is provided.

The median speed V_{1i} in m/s is given by

$$\frac{1}{V_{1i}} = \frac{1}{V_{mi}} + \frac{acon_i}{V_b - 2.5} - \frac{acon_i}{4.5}$$

where V_b is the road width in m.

$acon_i$ is the calibration constant for particular vehicle type i.

V_{mi} is the median speed for 7m. road for a particular vehicle type.

Using the above equation median speeds(V_{1i}) are evaluated for narrow, intermediate and two lane wide roads with assumed $acon_i$ values. Table 3.1 shows the 20 different vehicle types with their acon values, speeds at narrow, intermediate and two lane roads, and free speeds.

Figure 3.1 shows the median speed as a function of road width for some of the vehicle types.

Effect of horizontal curves: If the road includes a horizontal curve, the median speed V_{1i} must be reduced taking into account the horizontal radius. It is assumed as in the original model, that the curves with a mean radius $r > 1000$m do not effect the speed V_{1i}. If $r \leq 1000$m the median speed V_{2i} on the curve is obtained with the following expression, where speeds V_{2i} and V_{1i} are given in m/s

Table 3.1 aconi values for different vehicle types.

Vehicle type	Description	aconi	speed on narrow	Intermediate	two lane	free speed
1	Ambassador	Ø.Ø42	42.73	59.94	65	71.32
2.	Premeir	Ø.Ø43	43.23	61.52	67	73.92
3.	Maruti	Ø.Ø44	44.Ø9	63.92	7Ø	77.78
3.	Jeep	Ø.Ø4	41.15	55.86	6Ø	65.Ø7
4.	Tempo	Ø.Ø325	26.7Ø	31.ØØ	32	33.12
6.	Mini bus	Ø.Ø4	38.74	51.5Ø	55	59.23
7.	Bus	Ø.Ø35	42.83	56.35	6Ø	64.39
8.	Mini truck	Ø.Ø3	37.65	45.95	48	5Ø.35
9.	Small truck	Ø.Ø29	39.47	48.31	5Ø.5	53.35
1Ø.	Big truck	Ø.Ø275	41.16	5Ø.26	52.5	54.35
11.	Truck with trailer	Ø.Ø2	43.75	5Ø.85	52.5	54.35
12.	Farm tractor trailer	Ø.Ø15	18.91	19.18	2Ø	2Ø.19
13.	Bullock cart	Ø.ØØØ	18.8Ø	18.8Ø	18.80	18.8Ø
14.	Horse cart	Ø.ØØØ	18.ØØ	18.ØØ	18	18.ØØ
15.	Moped	Ø.Ø25	36.51	39.39	4Ø	4Ø.66
16.	Motor cycle	Ø.Ø175	53.4Ø	62.79	65	67.49
17.	Scooter	Ø.Ø175	39.12	43.93	45	46.12
18.	Autorickshaw	Ø.Ø175	27.26	29.52	3Ø	3Ø.52
19.	Cycle rickshaw	Ø.ØØØØ	11.ØØ	11.ØØ	11	11.ØØ
2Ø.	Bicycles	Ø.ØØØØ	14.ØØ	14.ØØ	14	14.Ø

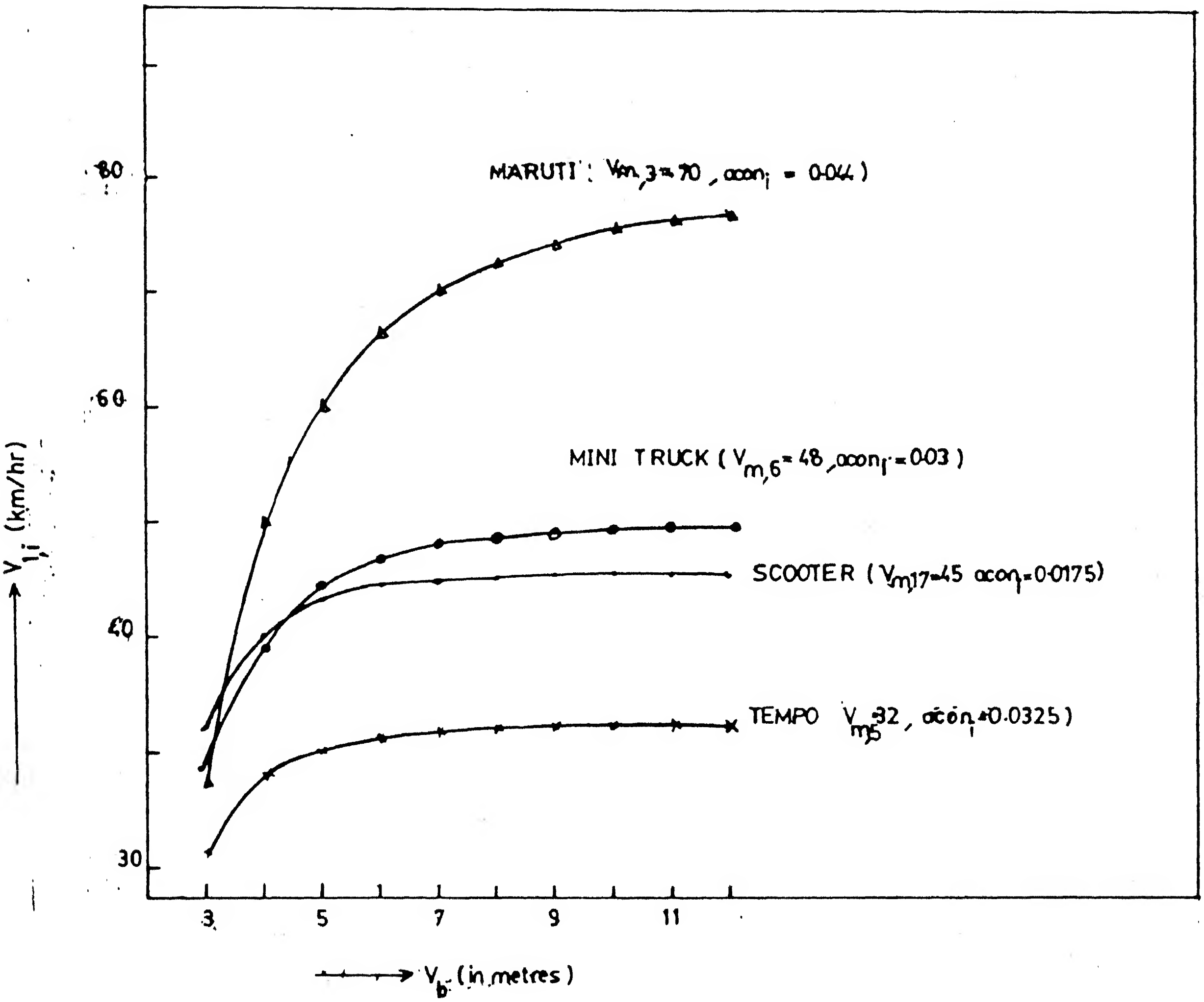


FIG-3-1 MEDIAN SPEED AS A FUNCTION OF ROADWIDTH FOR VEHICLE TYPES 3, 5, 6 AND 17

$$V_{2i} = \frac{1}{SQRT(\ (1/V_{1i})^2 + bcon_i\,(1/r - 0.001)\ )}$$

where r is the mean radius in m.

$bcon_i$ is the calibration constant for a vehicle type i

V_{1i} is the median speed for a vehicle type i on a straight road.

Table 3.2 shows the assumed $bcon_i$ values along with V_{1i} and corresponding speed V_{2i} at 100m curve values for all the vehicle types.

Figure 3.2 shows the median speed V_{2i} as a function of horizontal radius for some of the vehicle types.

Effect of speed limit: For a speed limit V_g, the median speed V_{3i} is obtained with the following expression. As explained above the effect of speed limit is assumed zero for some of the vehicle types.

$$V_{3i} = \frac{V_{2i}}{1 + c\ d^{z^2}}$$

where z is the ratio of the speed limit V_g to the free speed V_{1i}

i.e. $z = V_g/V_{1i}$

if $j \neq 11$ to 20

$= 0$ otherwise.

c and d are assumed same as explained in Chapter II

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Acc. No. A.104183

Table 3.2 bconi values for different vehicle types.

Vehicle type	Description	bconi	V_{1i}	speed V_{2i} at 100m. curve
1.	Ambassador	0.15	65	54.16
2.	Premier	0.18	67	53.62
3.	Maruti	0.2	70	53.99
4.	Jeep	0.14	60	51.63
5.	Tempo	0.05	32	31.44
6.	Mini bus	0.075	55	51.22
7.	Bus	0.1	60	53.66
8.	Mini truck	0.08	48	45.19
9.	Small truck	0.09	50.5	44.87
10.	Big truck	0.15	52.5	46.27
11.	Truck with trailer	0.175	52.5	45.43
12.	Farm tractor trailer	0.075	20	19.90
13.	Bullock cart	0.001	10.8	10.79
14	Horse cart	0.002	18.0	17.99
15.	Moped	0.01	40	39.94
16.	Motor cycle	0.03	65	63.17
17.	Scooter	0.02	45	44.38
18.	Auto rickshaw	0.005	30	29.95
19.	Cycle rickshaw	0.005	11	10.99
20.	Bicycle	0.005	14	13.99

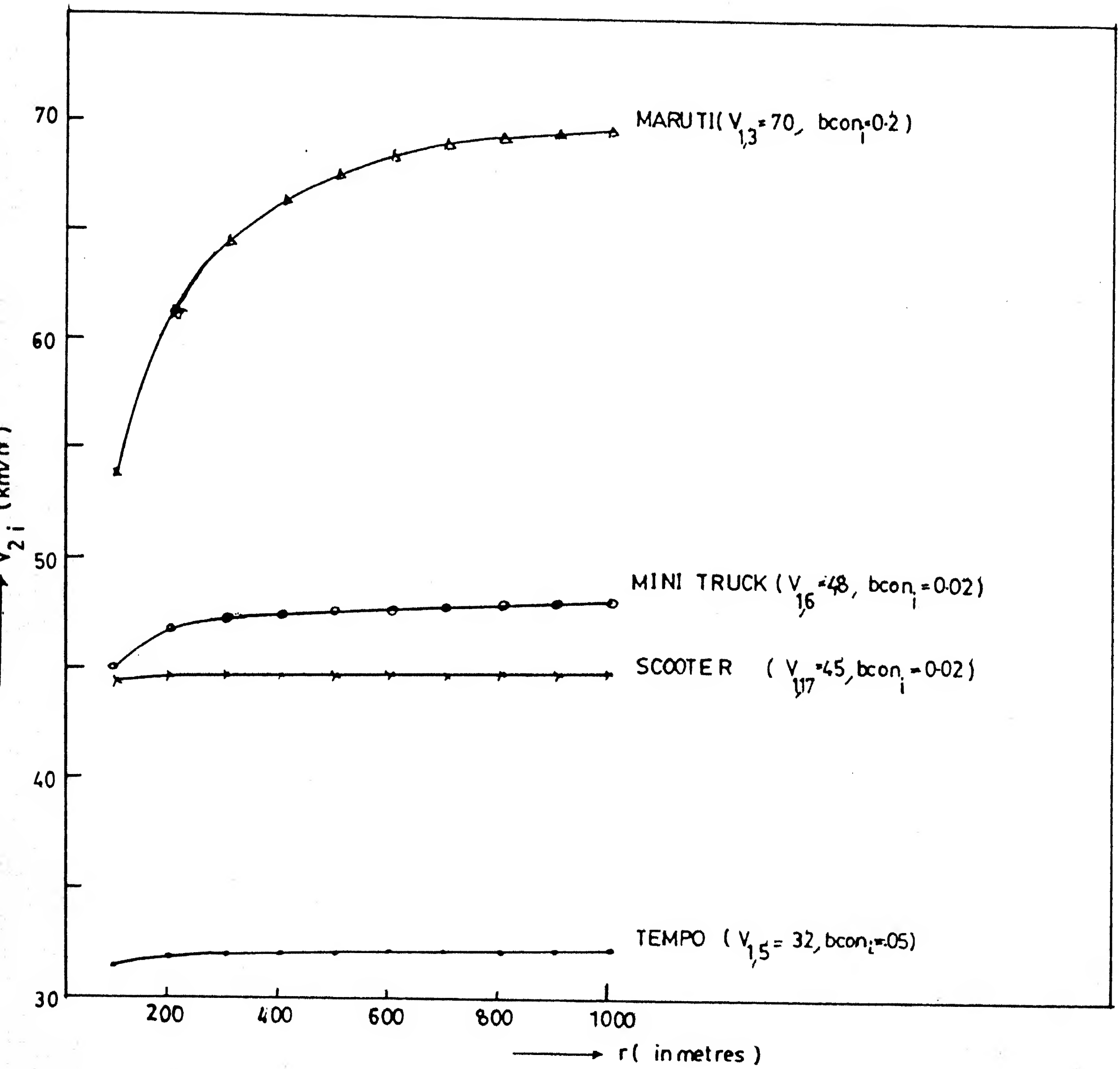


FIG 3.2 MEDIAN SPEED V_{2i} AS A FUNCTION OF HORIZONTAL RADIUS FOR VEHICLE TYPES 3,5, 6 AND 17

Measure of Transformation :

The measure of transformation for a particular vehicle type is assumed to be a function of q_n with median speeds V_{1i}, V_{2i}, and V_{3i} are considered as the weighing factors.

where q_n is the measure of rotation for road width, horizontal curve and speed limit.

The factors are assumed to be same as in the original model.

These factors are :

$q_1 = 0.5$ for road width

$q_2 = -0.8$ for horizontal curve

$q_3 = -2$ for speed limit.

the value Q_i can be calculated as follows

$$Q_i = \frac{q_1 k_1 + q_2 k_2 + q_3 k_3}{k_1 + k_2 + k_3}$$

where $k_1 = V_{0i} - V_{1i}$

$k_2 = 2(V_{1i} - V_{2i})$

$k_3 = 2.5(V_{2i} - V_{3i})$

3.3 Proposed Traffic Submodel :

The traffic submodel is modified to generate 20 different vehicle types with their traffic as well as vehicle characteristics. Since the calibrated distributions of BDS for each vehicle type are not available, these are calculated with the help of available distributions by changing the minimum and

maximum BDS. Since P/m distributions are not available for all these vehicle types they are also assumed with the help of the available data.

From road user cost study P/m distributions are available for car, bus, truck and two wheeler and BDS distributions are available for car, HMV and LMV. Table 3.3 shows the minimum BDS and maximum BDS for each vehicle type and their assumed distributions. Table 3.4 shows the assumed P/m distributions.

Calculation of BDS, P/m ratio, time of entry for each vehicle generated is same as in the original model. Calculation of entry speeds is slightly modified. For a free vehicle entry speed is equal to Ø.85*BDS, whereas for the constrained vehicle minimum BDS (BDS_{minpl}) among the platoon is calculated by excluding tempo, ADVs and two wheelers, and Ø.85*BDS_{minpl} is assigned to the vehicles which are considered for the calculation of BDS_{minpl} in the platoon.

3.4 Proposed Modifications to the Simulation Model :

The road data structure is modified as explained in section 3.2. The simulation model is modified to take into account block median speed and Q values for each vehicle type,to compute the freeblock speeds and freecross speeds. To determine the headlength retardation coefficient for each vehicle type $Deacc_i$ is considered. The proposed modification are explained below.

The computational procedure for DVQ_i and CVQ_i for each road block and for each vehicle type is as follows.

Table 3.3 BDS distributions for different vehicle types

Vehicle type	Description	Min BDS Km/h	Max BDS Km/h	Assumed variation
1.	Ambassador	40	100	Same as cars
2.	Premier	40	100	Same as cars
3.	Maruti	45	100	Same as cars
4.	Jeep	40	100	Same as cars
5.	Tempo	25	45	Same as cars
6.	Mini bus	40	80	Same as HMV
7.	Bus	50	85	Same as HMV
8.	Mini truck	35	75	Same as HMV
9.	Small truck	40	70	Same as HMV
10.	Big truck	40	70	Same as HMV
11.	Trucks with trailer	40	70	Same as HMV
12.	Farm tractor trailer	10	25	Same as HMV
13.	Bullock cart	10.8	10.8	Constant
14.	Horse cart	18	18	Constant
15.	Moped	30	35	Same as LMV
16.	Motor cycle	50	80	Same as LMV
17.	Scooter	35	65	Same as LMV
18.	Auto rickshaw	25	40	Same as LMV
19.	Cycle rickshaw	8	12	Same as LMV
20.	Bicycle	12	16	Same as LMV

Table 3.4 P/m ratios for different vehicle types.

Vehicle type	Description	Assumed P/m distribution
1.	Ambassador	Same as cars
2.	Premier	Same as cars
3.	Maruti	Same as cars
4.	Jeep	Same as cars
5.	Tempo	Same as bus
6.	Mini bus	Same as bus
7.	Bus	Same as bus
8.	Mini truck	Same as truck
9.	Small truck	Same as truck
10.	Big truck	Same as truck
11.	Truck with trailer	Same as truck
12.	Farm tractor trailer	Same as bus
13.	Bullock cart	Constant 10.00
14.	Horse cart	Constant 10.00
15.	Moped	Constant 5.00
16.	Motor cycle	Constant 10.00
17.	Scooter	Constant 7.00
18.	Auto rickshaw	Constant 5.00
19.	Cycle rickshaw	Constant 5.00
20.	Bicycle	Constant 10.00

$$DVQ_i = (IR_i)^{RQi} - (VØM_i)^{RQi}$$

$$CVQ_i = (CR_i)^{CQi} - (COM_i)^{CQi}$$

where IR_i is the median block speed for the vehicle type i

RQ_i is the value for the vehicle type i

CR_i is the median block crossing speed for vehicle type i.

CQ_i is the Q value for the crossing speed for vehicle type i.

The computational procedure for freeblock speed and freecross speed for each vehicle type is as follows.

$$\text{Free block speed} = (VØN^{RQi} + DVQ_i)^{1/(RQ)i}$$

$$\text{Free cross speed} = (CON^{CQi} + CVQ_i)^{1/(CQ)i}$$

where VØN is the basic desired speed of the vehicle.

CON is the basic desired crossing speed of the vehicle.

The procedure for calculating the headlength is as follows.

$$\text{Headlength} = \frac{(V_{forward} - V_{follow})^2}{2*Deacc_i} \quad \text{if } V_{forward} < V_{follow}$$

$$= Ø \text{ otherwise}$$

where $V_{forward}$ is the average speed of the preceding vehicle

V_{follow} is the average speed of the following vehicle.

$Deacc_i$ is the retardation coefficient for the following vehicle.

3.4.1 Proposed Procedure for Overtaking :

The original model considers the various alternative probabilities, since it is mainly designed for Swedish traffic conditions. The procedure is simplified by considering the Indian traffic system. The probability of accepting the free sight distance for overtaking is divided into the following different overtaking situations.

1. Type of overtaking
2. Type of overtaken vehicle

Type of overtaking 1. flying
2. accelerating

Overtaken vehicles are divided into 6 types. Type 1 contains the cars of all categories. Type 2 contains the mini tuck, mini bus and tempo. Type 3 contains the bus and truck. Type 4 contains the trailer trucks and tractors. Type 5 contains the the slow moving vehicles. Type 6 contains the all slow moving vehicles. The detailed classification is as follows:

type of overtaken vehicle 1. vehicle types 1 to 4
2. vehicle types 5,6,8 and 9
3. vehicle types 7 and 10
4. vehicle types 11 and 12
5. vehicle types 13 and 14
6. vehicle types 15 to 20

Here 20 different vehicle types are considered as explained in the previous Sections. In this procedure the obstruction whether it is natural or oncoming vehicle the effect

is assumed to be same. The type of the overtaken vehicle is only considered, irrespective of its speed. From RUCS study some of these probability distributions are available. Hence this procedure is modified to make use of the available data. The calculation of probabilities for overtaking are same as explained in the previous Chapter.

The detailed modifications considered for the simulation model, road submodel and traffic submodel are presented in this Chapter. The next Chapter presents various inputs to the traffic submodel and proposed road data structure. The various simulation experiments carried out with modified simulation model and the discussion of results are also presented in the next Chapter. Chapter V gives details of the various roads considered for the simulation experiments and the evaluation of road user cost under the present and proposed road conditions. Chapter VI presents the complete summary of the present work conclusions and and scope for the further work.

CHAPTER IV

EXPERIMENTS WITH THE MODIFIED SIMULATION MODEL

4.1 General

The simulation model allows the user to collect the statistics for any parameters of interest and thus the outputs of the simulation model are varied in nature. However parameters such as journey speed, spot speed and time headway are considered for the data collection. The available distributions of P/m ratio and BDS are explained in Section 4.2. The variations of assumed distributions and generated distributions are also shown in Section 4.3. Roads considered for the simulation experiments and their data structure is described in Section 4.3. The simulation experiments carried out with the modified simulation model under narrow and wide road conditions, and the results are described in Section 4.4.

4.2 Vehicle Data Structure :

Vehicle parameters are generated from the modified traffic submodel. The term parameters has been preferred to data because an individual vehicle has characteristics which, they are required as input to the model, cannot be realistically collected or generated as data, e.g. BDS, P/m ratio. The following are the vehicle parameters required for the operation of the model.

- Identification number
- Vehicle type
- Basic desired speed

- P/m ratio
- Entry time
- Entry coordinate
- Entry speed

Since the number of vehicle types are assumed to be 20 the BDS distribution and P/m ratio distributions are not available, at present, for all the vehicle types. The distributions are calculated with the help of the available distributions. Figure 4.1 presents available BDS distributions for vehicle types, car, HMV (trucks and buses) and LMV (motorcycle/ scooter). Figure 4.2 presents the available P/m distributions for car, truck, bus and assumed distribution for Maruti car. 1000 vehicles are generated each of 5% in both directions by using modified traffic submodel. Frequency distributions of BDS and P/m ratio for each vehicle type are evaluated for the generated traffic data. Then the comparison has been made between the assumed and the generated distributions for each vehicle type. Figure 4.3 to 4.11 presents the variation of assumed and generated distributions for some of the vehicle types.

4.3 Road Data Structure :

The road to be simulated must be described as a series of homogeneous road blocks, each having the same geometry and traffic regulations. The data required for each road block is as follows.

- Distance coordinate of the start of the block in meters
- Block length in meters

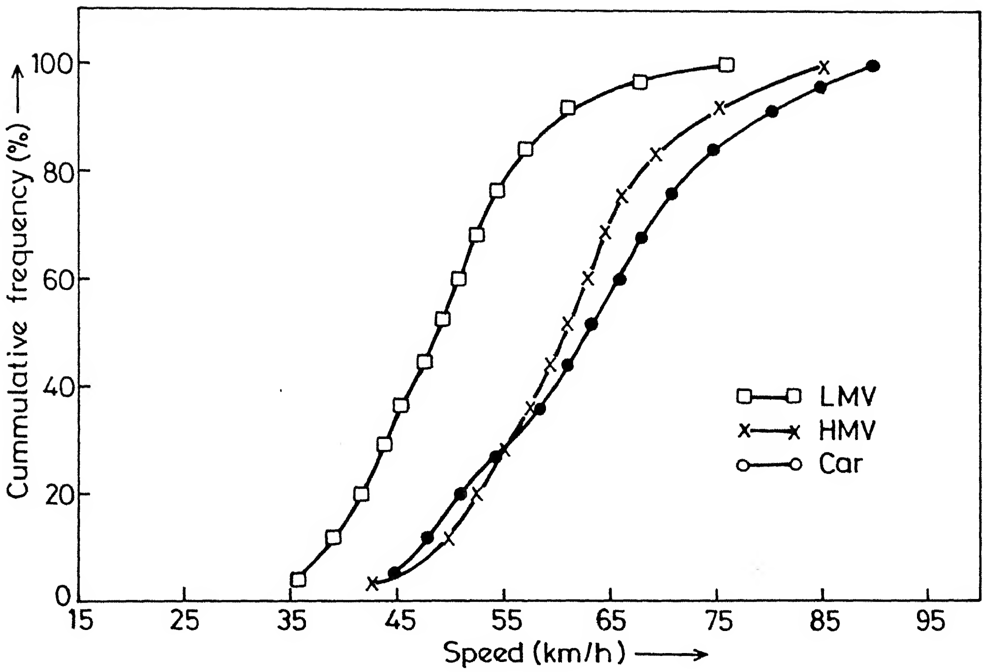


Fig.4·1 Distribution of basic desired speeds.

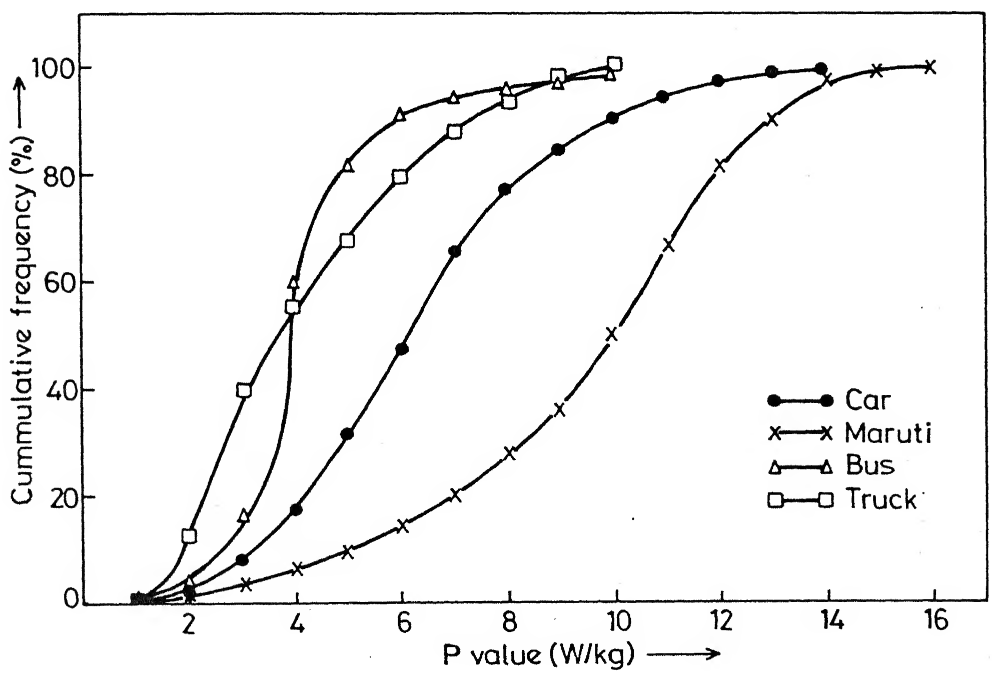


Fig.4·2 Distribution of Power/Mass ratio.

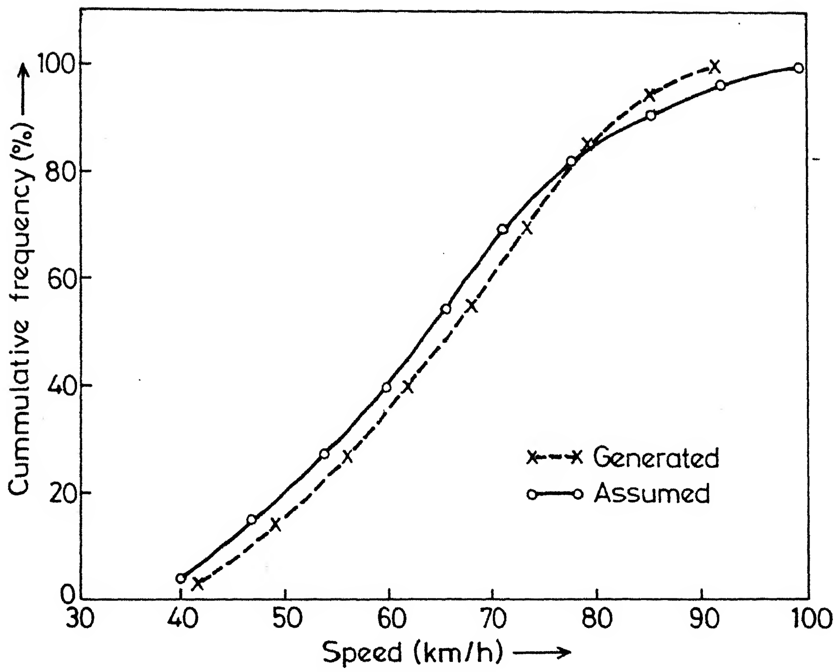


Fig. 4·3 Comparison of assumed and generated distributions of BDS for Ambassador car.

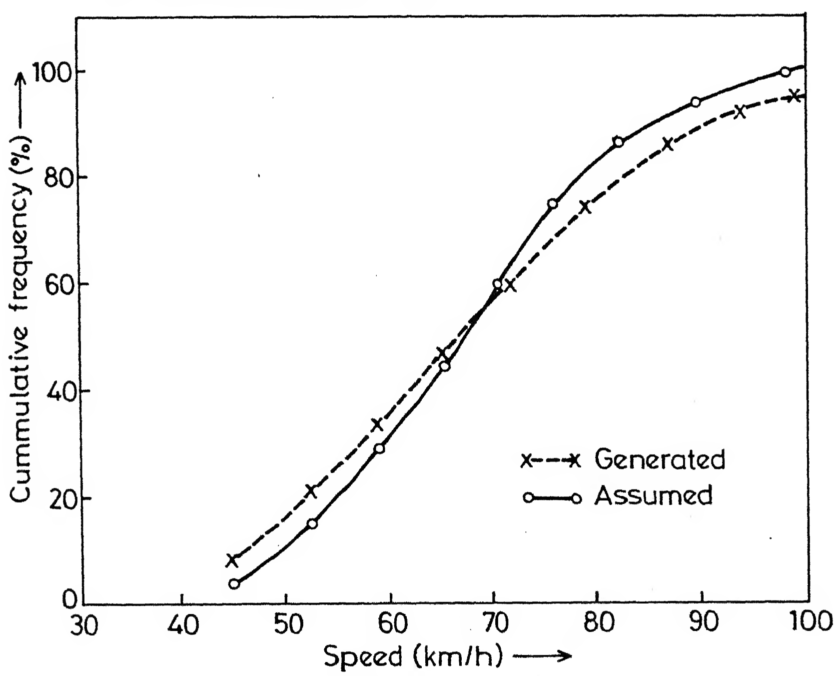


Fig. 4·4 Comparison of assumed and generated distributions of BDS of Maruti car.

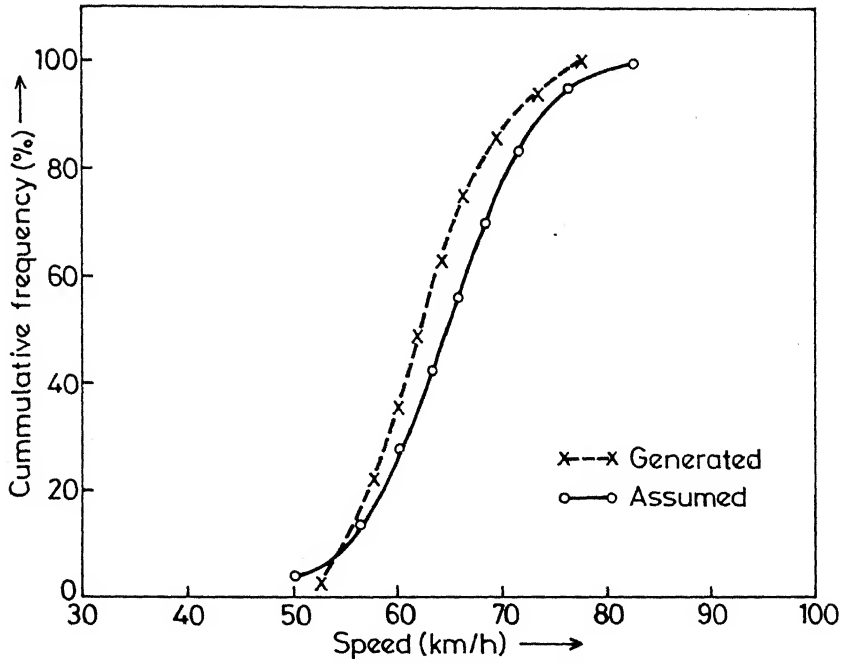


Fig.4·5 Comparison of assumed and generated distributions of BDS for bus.

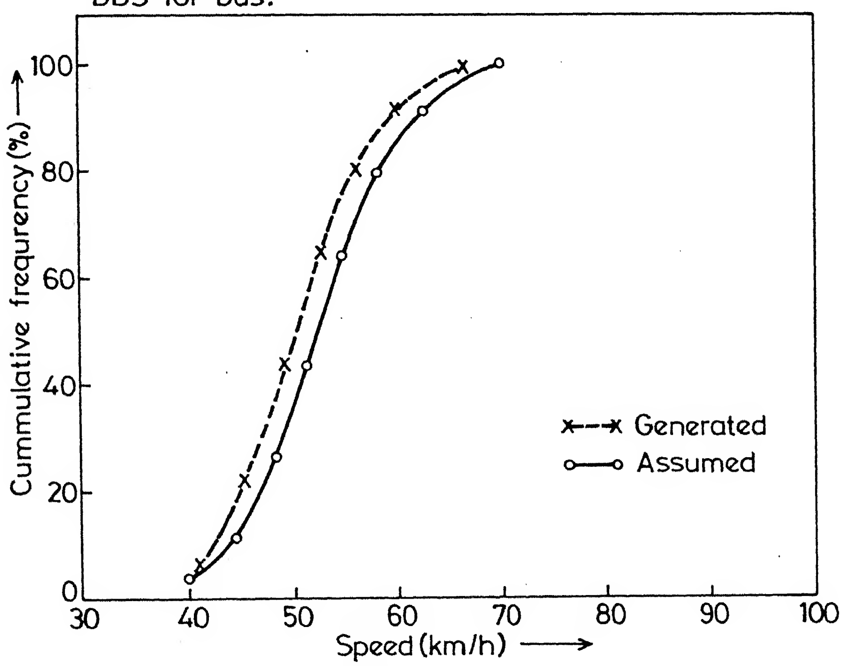


Fig.4·6 Comparison of assumed and generated distributions of BDS for big trucks.

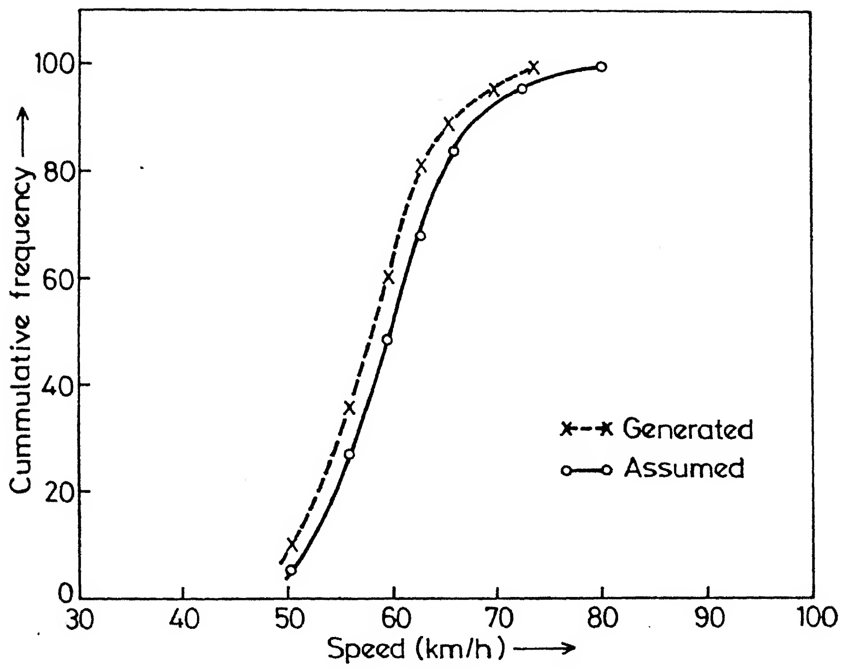


Fig.4·7 Comparison of assumed and generated distributions of BDS for Motor cycle.

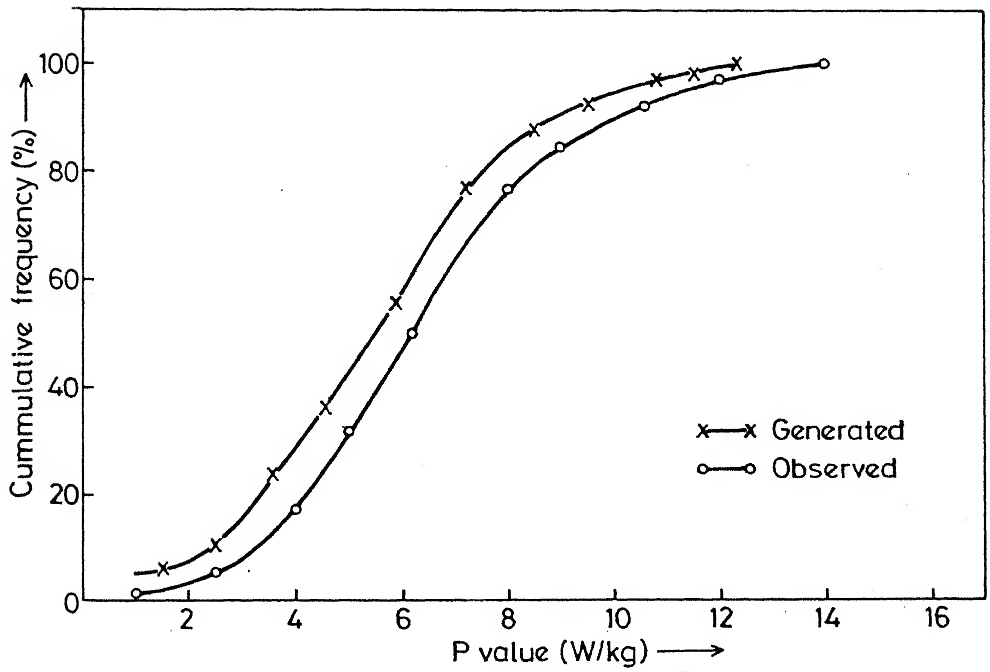


Fig.4·8 Comparison of assumed and generated distributions of P/m for Ambassador car.

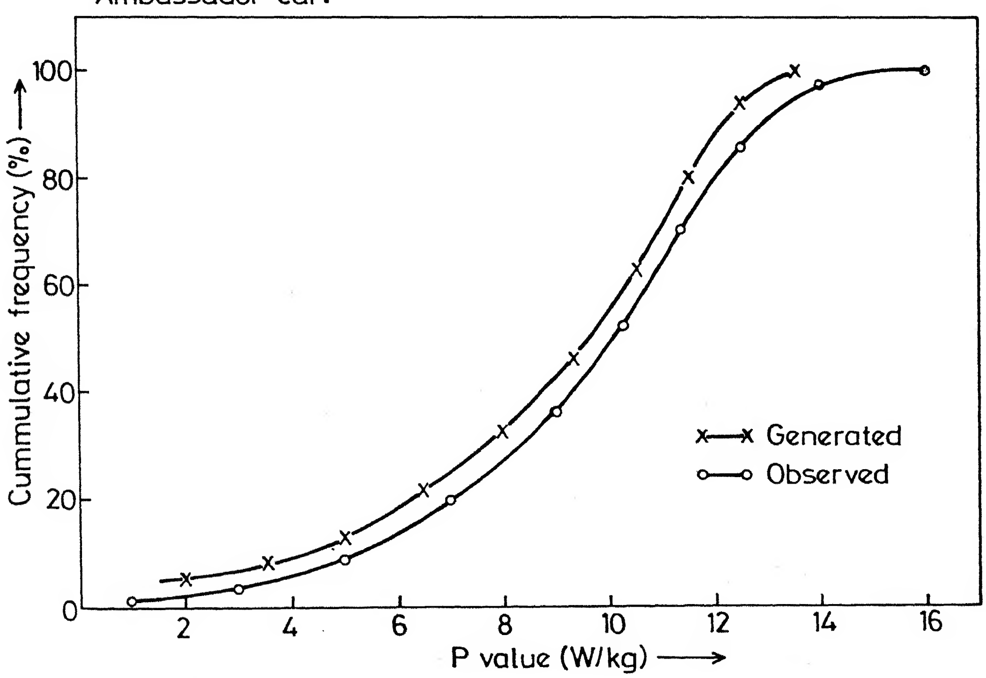


Fig.4·9 Comparison of generated and observed P/m distribution for Maruti car.

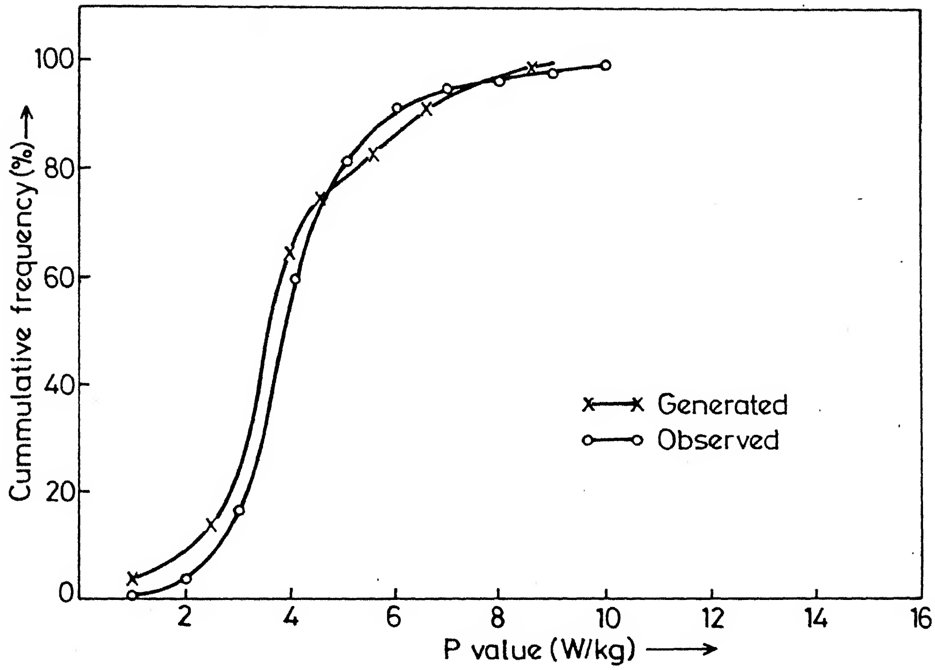


Fig. 4.10 Comparison of generated and observed P/m distribution for bus

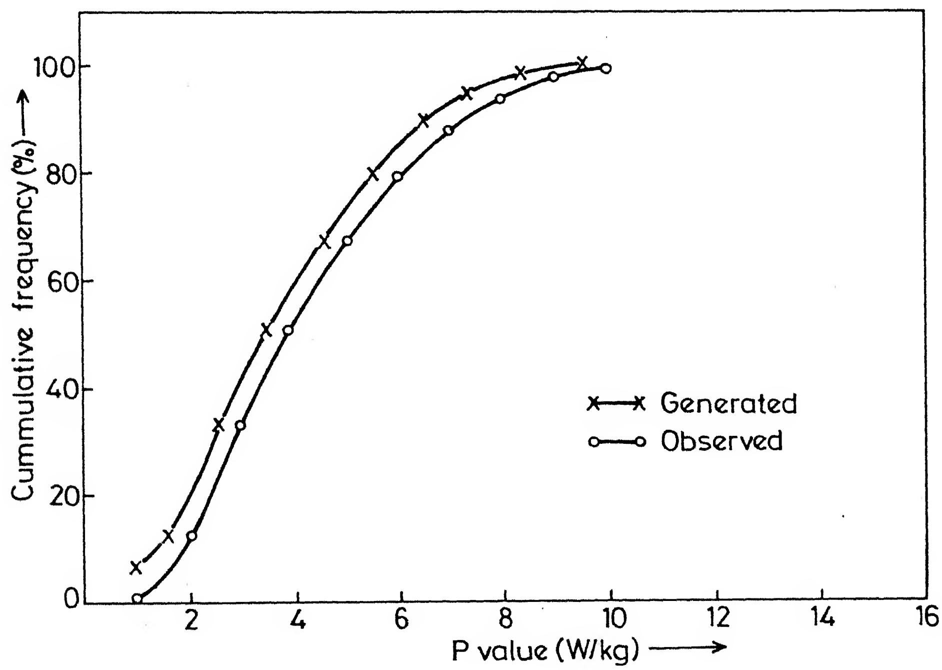


Fig. 4.11 Comparison of generated and observed P/m distribution for big trucks.

- Width of the road in meters
- Shoulders width in meters
- Radius of curvature in 10000/(radius in m)
- Speed limit in Km/h
- Slope in meters/km
- Road roughness in mm/km

A straght stretch of length 5 km is considered for the simulation experiments. The basic idea is to study the interactions between the various vehicle types and to evaluate the mean journey speed for each vehicle type. The details of the road under narrow and wide road condition are shown in Table 4.1. The median speed and the Q value for each vehicle type are obtained for each road block by accounting for the road geometry and speed limit factors as explained in chapter III.

4.4 Simulation Model Output :

As explained in the above section, the length of the road is 5km and is simulated for narrow and wide road conditions for 20 different vehicle types each consisting of 5%. Different flow levels are generated using modified traffic submodel. The road data is prepared for narrow and wide road by using the modified road submodel. At the end of each simulation run, the output file produced by the model gives the simulated movement of each vehicle along the road. Thus, there is a record for vehicle, giving

- Spot speed at data collection stations A, B and C
- Journey speeds in road sections AB, BC and AC

Table 4.1 Road Data for the Modified Simulation Model

Type	Narrow Road
1. Length of the road stretch	5km
2. Pavement width	3.6m
3. Shoulder width	nil (earthen shoulder)
4. Number of road blocks :	25
5. Average rise plus fall :	Ø.1494
6. Maximum horizontal curvature:	Ø.Ø (1ØØØØ/r)
7. Speed limit	65 km/h

Type	Wide Road
1. Length of the road stretch :	5km
2. Pavement width :	7.Øm (throughout)
3. Shoulder width :	nil (earthen shoulder)
4. Number of road blocks :	25
5. Average rise plus fall :	Ø.1494
6. Maximum horizontal curvature:	Ø.ØØ (1ØØØØ/r)
7. Speed limit :	85 km/h

r is the radius of curve in metres.

- Time headways at A, B and C
- Number of overtakings in sections AB, BC and AC

The information available in the output file can be processed at a later stage to study the traffic parameters of interest and obtain the relevant statistics. It is possible to analyze the output file as follows :

a) For any class of vehicle, and for any station (A, B or C), a histogram of time headways may be constructed, and the total number of observations, mean and standard deviations printed.

b) For any given class of vehicle , and for any station (A, B or C), a histogram of spot speeds may be calculated, and the total number of observations, mean and standard deviations printed.

c) For any class of vehicle, and for any road stretch (AB, BC or AÇ) a histogram of journey speeds, may be constructed, and the total number of observations, mean and standard deviations are printed.

Simulation experiments are performed under narrow and wide road conditions with traffic data generated for volumes ranging from 100veh/h to 500 veh/h to determine the journey speed for each type of vehicle and for all vehicle types. The model data are assumed accordingly. Three data points are considered in both the directions; time headway, mean journey speed and spot speeds are calculated for each vehicle type. Variations of mean journey speed over the whole stretch under narrow and wide road

conditions for some of the vehicle types are shown in Tables 4.2 and 4.3 respectively. Regression equations are developed for the mean journey speeds under narrow and wide road conditions. The regression equations show that mean journey speed is function of the flow in veh/h. The details of the regression equations are given Table 4.4. From Table 4.2 and 4.3 it can be seen that the vehicle types like Maruti car is having more journey speed compared to truck and tempo. Hence it can be concluded that the results are consistent with the assumed distributions and constants. The regression relations are shown in Fig. 4.12. These figures shows a clear trend of reduction in mean journey speed with an increase in traffic volume.

The detailed description of the experiments carried out with the modified simulation model under narrow and wide road conditions has been presented in this Chapter. The proposed road data structure and traffic data structure are also explained in this Section. The detailed discussion have been given on the results obtained .Next Chapter presents the various simulation experiments carried out on different roads, evaluation of speed flow relations and determination of road user cost under the existing and the proposed road conditions.

Table 4.2 Journey Speeds at Different Flow Levels for the Case of Narrow Road With the Modified Simulation Model

Vehicle type	Flow level: 100 veh/hr Mean Speed	100 veh/hr S.D	200 veh/hr Mean speed	200 veh/hr S.D	300 veh/hr Mean speed	300 veh/hr S.D	400 veh/hr Mean speed	400 veh/hr S.D
Ambassador	27.66	7.10	24.93	11.50	20.01	6.90	14.88	6.99
Maruti	29.23	16.30	27.50	13.22	21.66	10.01	15.16	3.98
Tempo	22.88	7.24	21.11	7.40	19.21	8.50	12.81	6.80
Bus	26.64	16.30	24.44	16.23	20.37	10.10	14.97	5.90
Premier	27.22	10.50	24.25	7.50	20.38	13.25	16.57	5.80
Big Truck	22.50	8.50	20.05	7.50	19.74	8.50	12.83	6.35
Tractor	10.85	0.20	10.80	0.70	10.18	1.90	8.70	6.30
Motor cycle	26.33	15.40	22.75	14.80	20.96	10.40	15.25	11.90
All other types	25.45	12.80	22.75	11.00	17.09	10.90	14.22	11.90

Table 4.3 Journey Speeds at Different Flow Levels for the Case of Wide Road With the Modified Simulation Model

Vehicle type	Flow level							
	200 veh/hr		300 veh/hr		400 veh/hr		500 veh/hr	
	Mean Speed	S.D	Mean speed	S.D	Mean speed	S.D	Mean speed	S.D
Ambassador	54.80	11.20	51.30	14.25	46.58	13.10	39.13	13.85
Maruti	62.40	18.50	62.37	9.60	48.43	18.93	38.42	16.00
Tempo	31.55	8.85	31.44	7.75	28.88	9.58	26.25	4.25
Bus	55.54	9.65	50.00	14.00	46.43	10.40	37.13	15.25
Premier	54.95	11.70	53.90	11.35	48.26	14.55	40.07	16.25
Big Truck	44.78	5.05	42.22	6.50	41.62	9.50	28.0[illegible]	7.35
Tractor	16.73	1.90	16.71	2.30	15.76	2.70	15.63	2.30
Motor cycle	53.00	7.00	50.54	10.80	41.66	9.50	37.85	17.45
All other types	35.99	20.30	33.38	20.00	25.62	17.20	23.72	17.55

Table 4.4 Speed Flow Relation for the case of Modified Simulation Model

For Wide Road:

Speed	=	48.439 - 0.0374*Flow (23.866)
R squared value	=	0.922679
Standard Error of Y estimate	=	1.7091
Standard error of coefficient	=	0.007643

For Narrow Road

Speed	=	30.825 - 0.0428*Flow (57.388)
R squared value	=	0.99565
Standard Error of Y estimate	=	0.44749
Standard error of coefficient	=	0.00200

() F Calculated Value

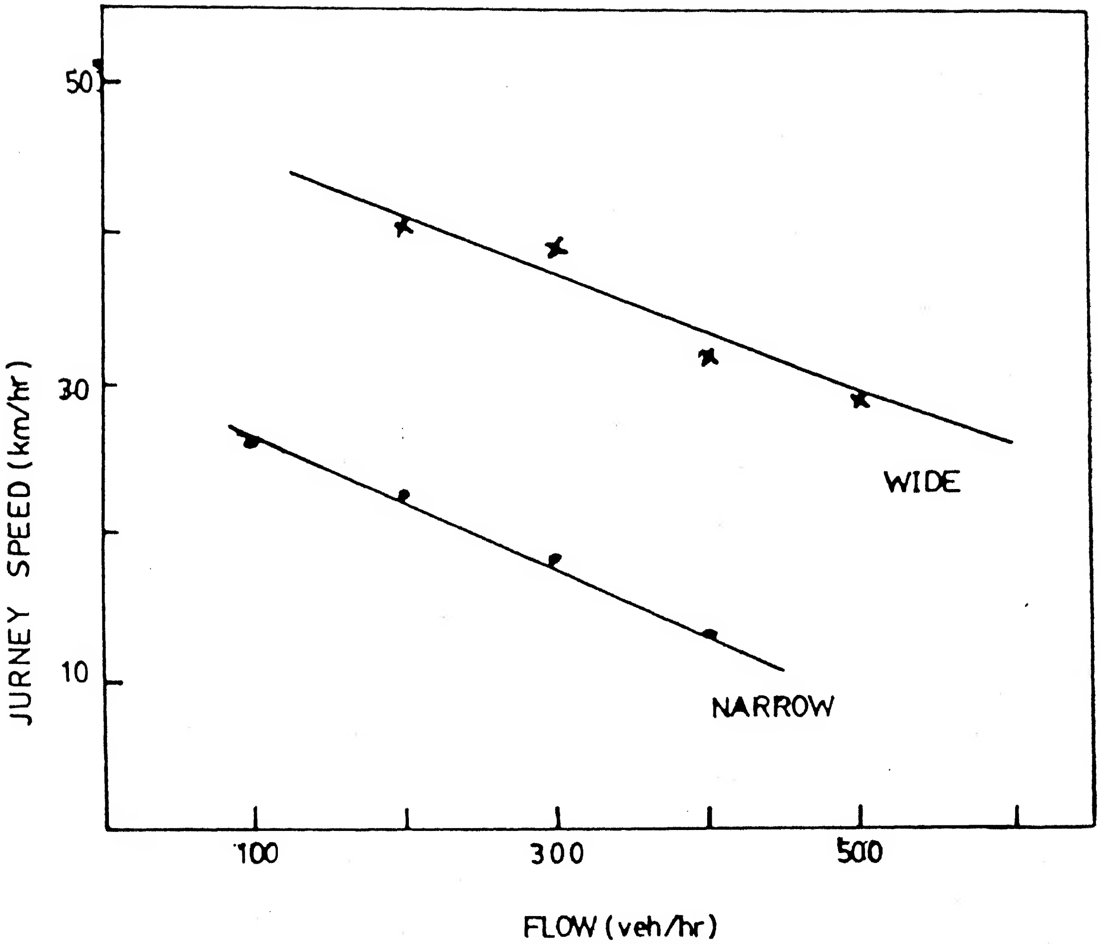


FIG. 4.10 SPEED FLOW RELATIONS FOR THE CASE OF MODIFIED SIMULATION MODEL

CHAPTER V

SIMULATION EXPERIMENTS ON INDIAN ROADS

5.1 General

Three typical road stretches are considered on three different highways for simulation experiments. One of these stretches is on a hilly terrain having steep slopes and free of slow moving vehicles. The second one is on a plain terrain, but the traffic contains considerable percentage of slow moving vehicles. The third one is also on a flat terrain having a good amount of traffic and the presence of slow moving vehicles is less compared to the second stretch. The simulation experiments are carried out under the existing conditions of road, for the present and for the assumed future growth of traffic. The simulation experiments are also carried out by changing the road conditions (i.e. from narrow road to two lane wide road), under the present as well as for the future traffic. Speed flow relationships are obtained for different roads under different conditions, and the road user's cost is evaluated using the speed flow relations. The existing and proposed road data, and the traffic details (i.e. percentage of each vehicle type and assumed growth) are obtained from the respective highway departments. Peak hour traffic is considered for the simulation experiments. To determine the road users cost, the hourly distribution of average daily traffic (ADT) has been adopted from the study conducted by Maharashtra Engineering Research Institute (1980), is presented in Table 5.1. All simulation experiments are carried out with the existing models.

Table 5.1 Hourly Distribution of ADT

Hour	Flow (percent of ADT)
Ø - 1	3.39
1 - 2	2.99
2 - 3	1.6Ø
3 - 4	1.53
4 - 5	1.93
5 - 6	1.8Ø
6 - 7	2.93
7 - 8	3.Ø6
8 - 9	5.Ø6
9 - 1Ø	6.72
1Ø - 11	6.72
11 - 12	5.32
12 - 13	5.66
13 - 14	5.46
14 - 15	6.19
15 - 16	4.46
16 - 17	6.19
17 - 18	6.32
18 - 19	6.Ø5
19 - 2Ø	5.32
2Ø - 21	3.26
21 - 22	3.66
22 - 23	2.2Ø
23 - 24	2.26

Section 5.2 describes the various simulation experiment carried out on a stretch of road on NH7 under the narrow and wide road conditions. The road users cost under these conditions is also presented in this section. Section 5.3 explains the simulation experiments and the evaluation of road users cost under narrow and wide road conditions on the section of NH15 road. Section 5.4 presents the various simulation experiments carried out and the evaluation of road users cost on the stretch of NH28 road.

5.2 Simulation Experiments on a Section of NH7 :

A ghat section of 6.7 km length on NH7, between Nagpur and Hyderabad is considered for the simulation experiments. The existing carriage way in this section is single lane i.e. 3.6m wide, except widened to 0.2m at some isolated places for small lengths not more than 150m as metal shoulders. Hence the presence of shoulders is ignored in preparing the road data. The existing road has many sharp curves, kinks and hair pin bends. The existing gradients are as steep as 1 in 17 and 1 in 20. All the existing curves in the hair pin bends are falling short of National Highway standards. The detailed road data is shown in Table 5.2.

The traffic composition is mainly of heavy moving vehicles, which constitutes 72% of the total traffic. The two wheelers and cars constitutes 13% and 15% respectively. Different flow levels varying from 100 vehicles per hour to 300 vehicles per hour are

Table 5.2 Road Data for NH7

Type	Narrow road
1. Site	NH7 - (Nagpur to Hyderabad) (257.00km to 263.40km)
2. Length of the road stretch	6.4 km.
3. Pavement width	3.6 m.
4. Shoulder width	nil (earthen shoulder)
5. Number of road blocks	110
6. Avrage rise plus fall	31.5591
7. Maximum radius of curvature	1111.1 (10000/r)
8. Speed limit	65 km/h

Type	Proposed wide road
1. Site	NH7 - (Nagpur to Hyderabad) (256.71 km to 263.21 km)
2. Length of the road stretch	6.5 km.
3. Pavement width	7.0 m.
4. Shoulder width	nil (earthen shoulder)
5. Number of road blocks	60
6. Average rise plus fall	30.13547
7. Maximum horizontal curvature	563.38(10000/r)
8. Speed limit	85 km/h

r radius of curve in metres.

considered for simulation experiments. The detailed traffic data considered for the simulation experiments is shown in Table 5.3. The road conditions are assumed to be the same for different flow levels. The mean journey speed for each vehicle type and for all the vehicle types is calculated. Table 5.4 shows the mean journey speeds at different flow levels. The regression equations are developed for the existing road for each vehicle type. The details of the regression equations are given in Table 5.5.

The same traffic is simulated on the proposed 7.0m wide road. The proposed road contains the improved horizontal alignment. The curves, kinks and gradients are up to the I.R.C (Indian Road Congess) standards. The road conditions are assumed same for different flow levels. The detailed proposed road data is presented in Table 5.2.

Simulation experiments are carried out for different flow levels as shown in Table 5.3, and mean journey speeds for each vehicle type and for all vehicle types under different flow levels are obtained. Table 5.4 presents the mean journey speeds under the proposed road conditions. Speed flow relations are obtained for each vehicle type with linear regression. The details of the regression equations are given in Table 5.6.

Figure 5.1 shows the speed flow relations under the existing and proposed road conditions, for all vehicle types and for vehicle type car and HMV under different flow levels. From the figure it is quite clear that the speeds are high on wide road conditions. From the figure it can also be seen that the speeds

Table 5.3 Traffic Data For NH7

Peak hourly flow	No. of cars	No. of HMVs	No. of two wheelers
100	15	72	13
122	18	88	16
150	22	108	20
222	33	160	29
266	40	191	35
300	45	216	39

Table 5.4

Journey Speeds (km/h) at Different Flow Levels for NH7 - Narrow Road

Flow level	All Vehicle types Mean speed	S.D	Car Mean speed	S.D	HMV Mean speed	S.D	Two wheelers Mean speed	S.D
100	32.15	5.05	34.81	4.23	32.90	4.70	27.6	3.35
122	31.15	4.65	34.35	4.70	32.04	3.92	27.18	3.90
150	30.10	3.75	31.89	3.30	30.60	3.25	26.60	3.35
222	26.20	3.25	27.59	4.35	26.44	2.80	23.83	2.40
266	24.80	2.90	25.91	3.35	25.00	2.70	22.81	2.55
300	20.45	5.50	20.83	4.75	20.58	5.60	19.34	4.40

Journey Speeds (km/h) at Different Flow Levels for NH7 - Wide Road

Flow level	All Vehicle types Mean speed	S.D	Car Mean speed	S.D	HMV Mean speed	S.D	Two wheelers Mean speed	S.D
100	39.85	7.10	42.13	5.90	41.00	6.40	34.14	6.10
124	39.80	6.75	41.72	5.90	40.05	6.10	33.75	6.05
150	38.85	5.65	40.55	4.65	39.69	4.85	33.50	6.05
222	38.70	5.65	38.84	6.05	39.48	5.10	33.08	5.70
266	37.60	5.20	37.81	5.20	38.27	4.75	32.88	5.40
300	36.60	4.70	36.93	4.55	37.21	4.85	32.19	4.10

Table 5.5

Speed Flow Relations for Vehicle Types on NH7 for the Case of Narrow Road

---

Car

$Speed_{car}$	= 41.928 - 0.06564*Flow (131.5465)
R squared	= 0.97049
Standard Error of Y estimate	= 1.0422
Standard Error of Coefficient	= 0.00572

HMV

$Speed_{HMV}$	= 39.077 - 0.057675*Flow (135.675)
R squared	= 0.97136
Standard Error of Y estimate	= 0.90164
Standard Error of Coefficient	= 0.00495

All Vehicle Types

Speed	= 38.1306 - 0.05481*Flow (115.948)
R squared	= 0.9668
Standard Error of Y estimate	= 0.92693
Standard Error of Coefficient	= 0.00509

()F calculated value

Table 5.6

Speed Flow Relations for Vehicle Types on NH7 for the Case of Wide Road

---

Car

$Speed_{car}$	= 44.7Ø8 - Ø.Ø26Ø9*Flow (83Ø.791)
R squared	= Ø.99521
Standard Error of Y estimate	= Ø.16484
Standard Error of Coefficient	= Ø.ØØØ91

HMV

$Speed_{HMV}$	= 42.9141 - Ø.Ø1792*Flow (54.215)
R squared	= Ø.93129
Standard Error of Y estimate	= Ø.44312
Standard Error of Coefficient	= Ø.ØØ243

All Vehicle Types

Speed	= 41.4892 - Ø.Ø15Ø7*Flow (45.661)
R squared	= Ø.9194
Standard Error of Y estimate	= Ø.4Ø62
Standard Error of Coefficient	= Ø.ØØ223

() F calculated value

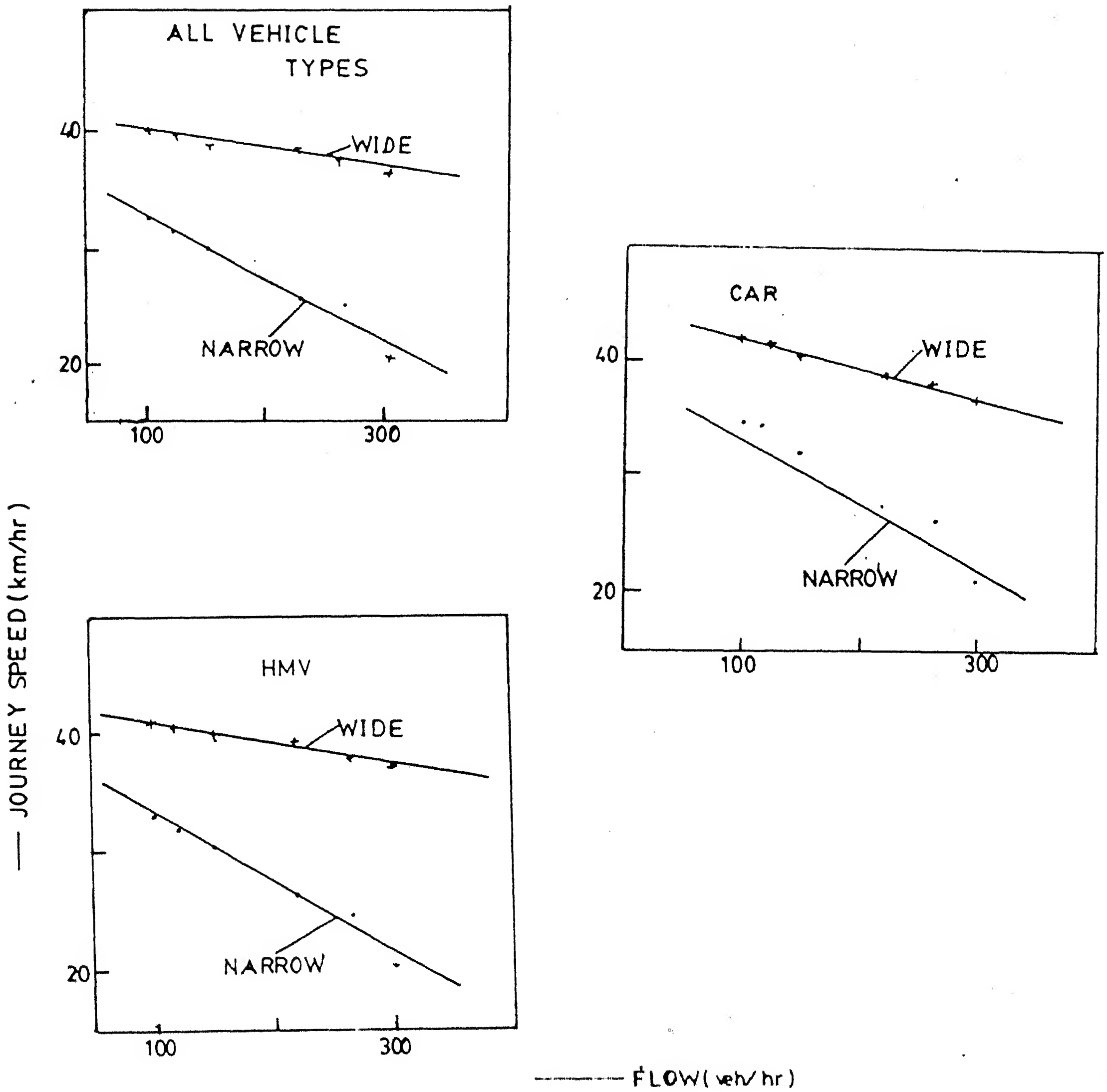


FIG 5.1 SPEED FLOW RELATIONS FOR NH7

reduce much faster with flow in the narrow road conditions and this may be mainly due to the adverse road conditions which are prevailing at present and severe traffic interactons on these roads.

5.2.1 Estimation of Road User Cost

The speed flow relationships as obtained above under the existing and the proposed road conditions are used to evaluate the road user costs. HDM model is used for evaluating the road user costs under the effect of traffic congestion. It is assumed that road is maintained in same condition throughout the analysis period with the surface roughness of the same value. It calculates vehicle operating costs for 6 different types of vehicle categories, i.e. Ambassador car,Premier, Jeep ,Tata truck, Beaver truck and passenger bus. From the car category it is assumed that Ambassador, Premier and Jeep constitutes 75%, 15% and 10%. From HMV category it is assumed that Tata truck, Beaver truck and bus constitutes 80%, 10% and 10% respectively.

Simulation experiments are conducted on average daily traffic(ADT) of 1500 vehicles per day in the base year, gradually increasing to 4800 vehicles per day during the analysis period of 20 yrs. From Table 5.1 it can be seen that the peak hour volume, 6.72 percent of ADT, is present in the morning hours between 9 AM and 11 AM. Thus the experiments are conducted for peak hourly flow of 100 vehicles per hour (approximate) in the base year to 320 vehicles per hour (approximate). The vehicle characteristics such as type, fuel type, power, gross weight

etc., are presented in Table 5.7. The unit vehicle operating costs used in the model are presented in Table 5.8. The results obtained from the simulation runs under narrow and wide road conditions are presented in Figures 5.2 to 5.5.

It can be seen from Figure 5.2 that the fuel consumption cost for Ambassador car and bus are increasing in the case of narrow road and decreasing in the case wide road. This can be due to the fuel consumption costs are high at higher and lower operating speeds. The cost is minimum at certain speed and this speed is called optimum speed. Hence it can be concluded that in the case of narrow road the speeds are left to the optimum speed and in the case of wide road the speeds are right to the optimum speed. In the case of trucks it can be concluded that the speeds under both the conditions are to the left of optimum speed.

Figure 5.3 presents the total running costs for all the vehicle types. The total running costs include fuel consumption, oil consumption, tyres, spare parts, maintenance labour, depreciation and interest. The method of computing the depreciation for Ambassador and bus has been the constant vehicle life method. In this method the vehicle life is constant irrespective of vehicle speed. Hence the total running cost follows almost the same pattern as fuel cost. But in the case of Tata truck the method for calculation of depreciation and interest is assumed as Modified TRRL-Kenya method. This method assumes that annual vehicle depreciation, on average can be attributed to two sources: first, the loss in resale value of the vehicles over the year, and second, the physical scrappage of

Table 5.7 Vehicle Characteristics

Character	Ambassador car	Tata truck	Bus
Fuel type	Petrol	Diesel	Diesel
BHP	50.0	112.0	112.0
Gross weight(ton)	1.5	1.5	1.5
Equivalent axle factor	0.0	0.96	0.96
No. of passengers	6	0	45
Annual operating hours	1000	2400	2400
Annual kilo-meterage driven	20200	90000	75000
Average life	5	6	6

Table 5.8 Unit Vehicle Operating Costs

Cost	Ambassador car	Tata truck	Bus
Fuel (Rs/lt)	7.90	3.75	3.75
Engine oil (Rs/lt)	16.90	16.90	16.90
New vehicle	106250.00	218750.00	373750.00
Tyres (Rs/tyre)	1060.00	4375.00	4375.00
Maintenance labour (Rs/hr)	4.15	4.15	4.15
Passenger time (Rs/hr)	20.00	0.00	5.65
Cargo (Rs/hr)	2.50	2.50	2.50
Annual overheads(%)	17.00	17.00	17.00
Interest rate(%)	12.00	12.00	12.00

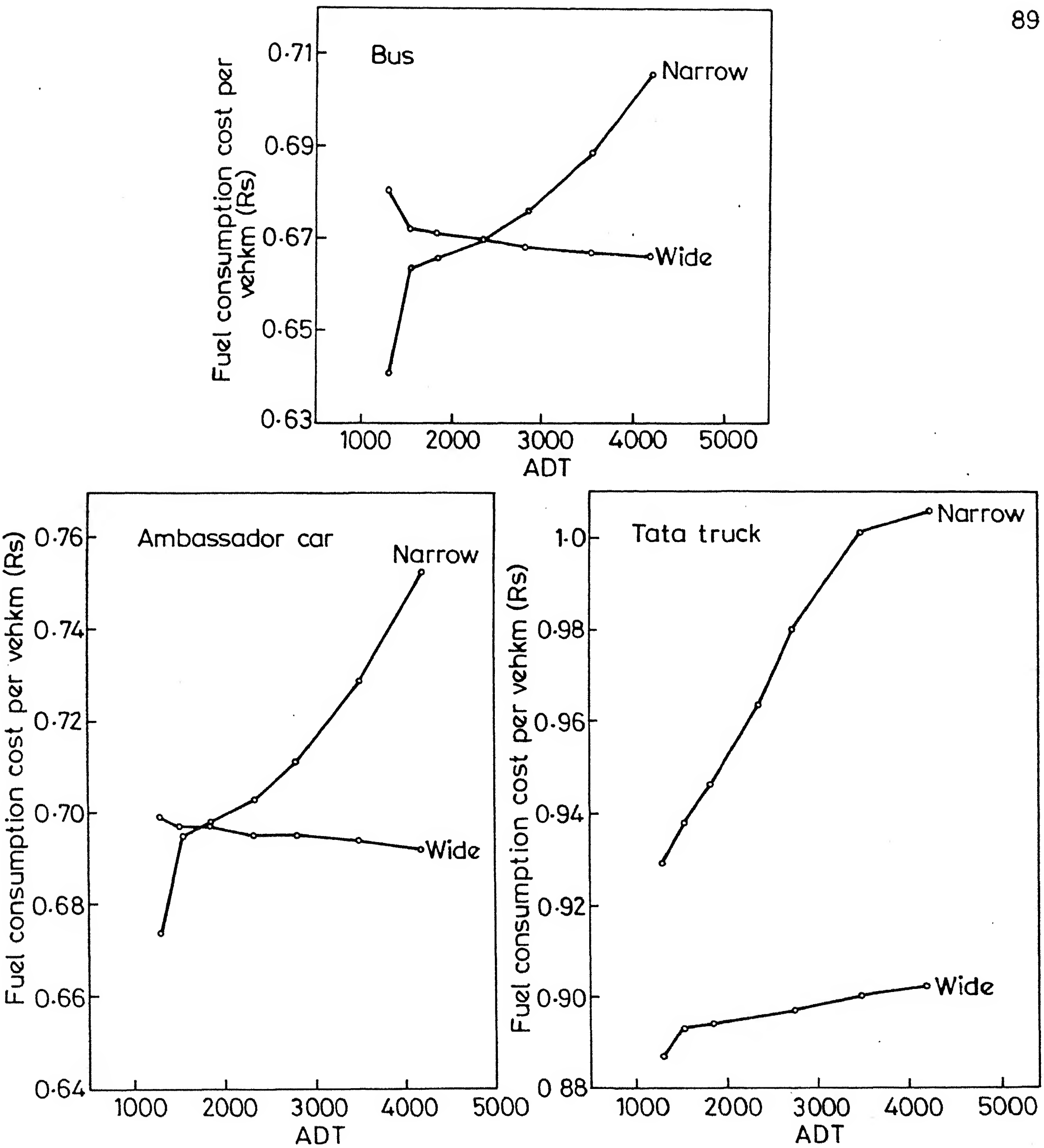


Fig.5·2 Fuel consumption cost per vehkm (Rs) vs ADT for NH7 under narrow and wide road conditions.

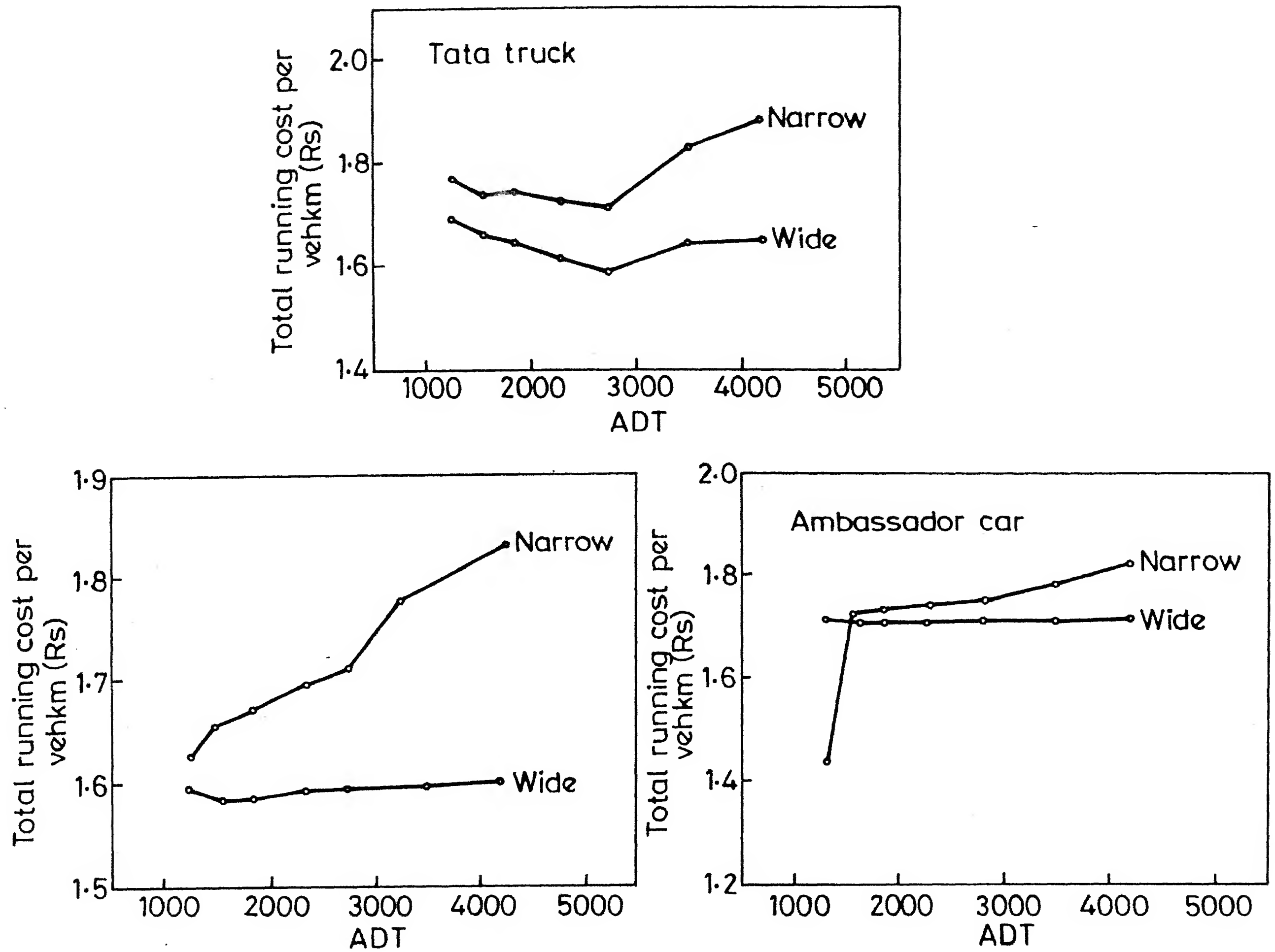


Fig.5·3 Total running cost per vehkm (Rs) vs ADT for NH7 under narrow and wide road conditions.

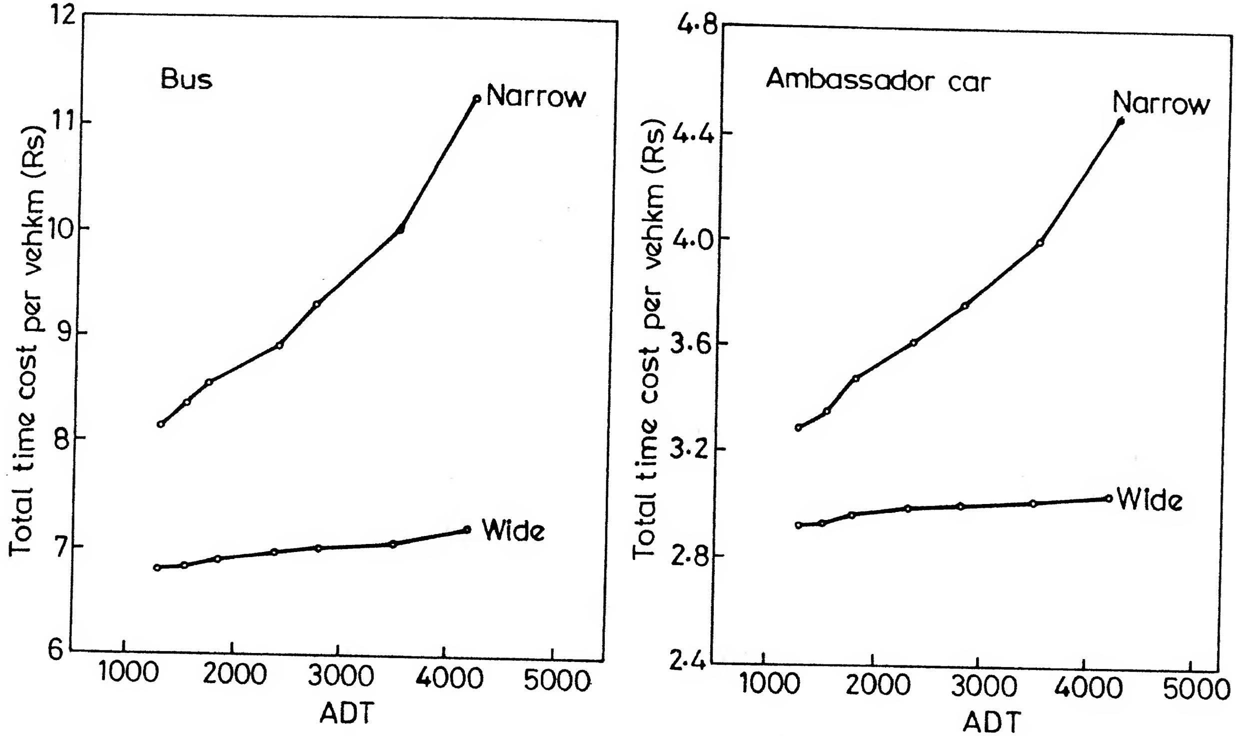


Fig.5.4 Total time cost per vehkm (Rs) vs ADT for NH7 under narrow and wide road conditions.

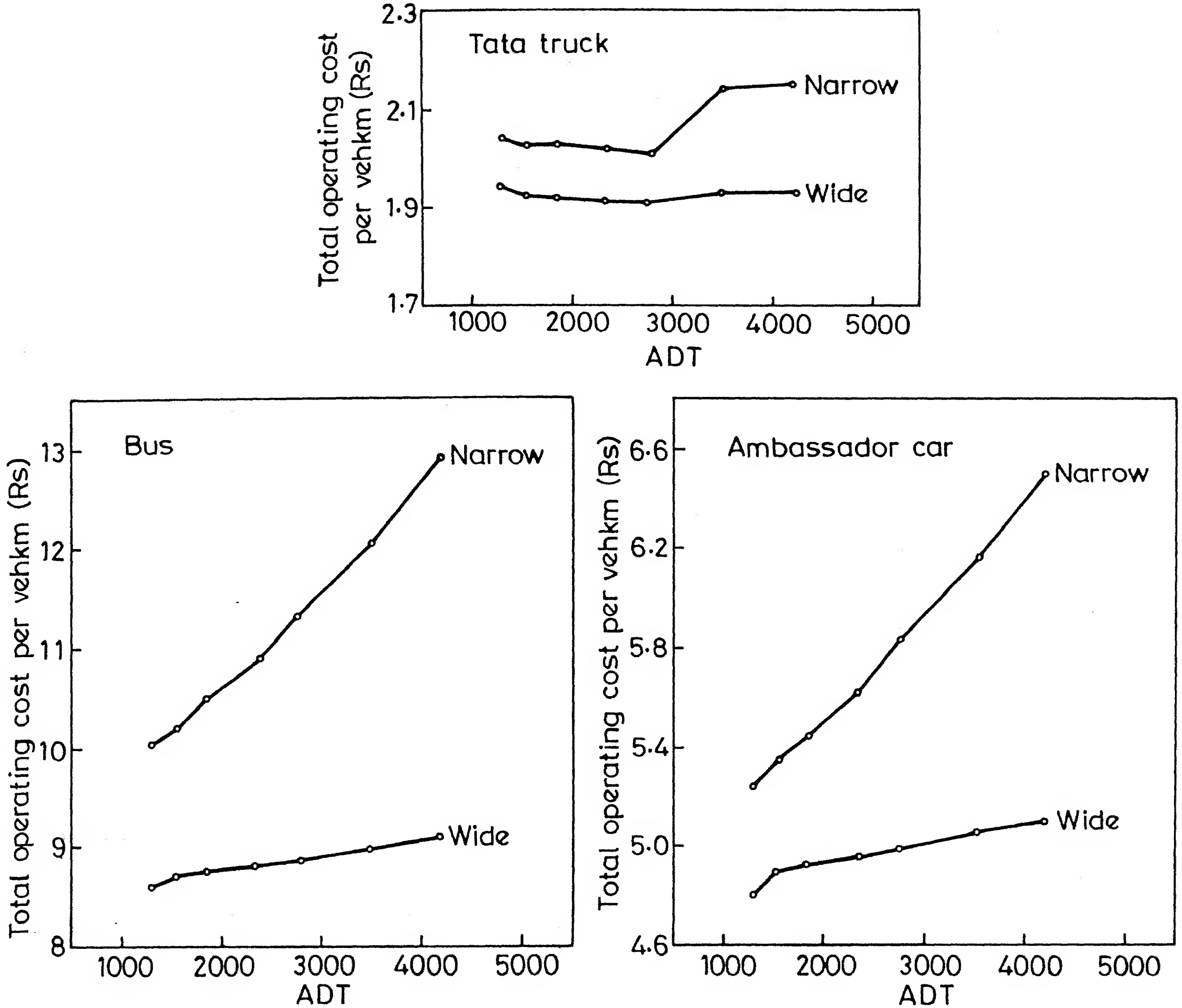


Fig. 5·5 Total vehicle operating cost per vehkm (Rs) vs ADT for NH7 under narrow and wide road conditions.

some vehicles in the regional or national fleet (due to collisions, major mechanical breakdowns etc.,). Hence in the initial years the effect due to depreciation and interest is less. Hence it follows the same pattern as that of fuel consumption cost. As the depreciation and interest costs are dominating the total running cost increases.

Figure 5.4 shows the total travel time costs for the Ambassador car and bus. The total travel time cost includes the time value of passengers and the time value of cargo. The travel time cost for Tata truck is maintained at a constant minimum value (0.004 Rs/km). From this Figure it can be seen that in the case of narrow roads the costs are increasing at alarming rate, which is quite true.

The total vehicle operating costs for all vehicle types are shown in Figure 5.5. The total vehicle operating cost includes the running cost and travel time cost. It could be observed that the vehicle operating costs are increasing under both the conditions for vehicle types Ambassador car and bus, thus indicating the effect of travel time. The reduction in speeds at higher volumes reduces the fuel consumption cost and other running cost components, while the travel time costs increases rapidly for narrow roads. Tata truck shows a similar trend as running costs since the travel time costs are assumed constant.

5.3 Simulation Experiments on a Section of NH15 Road :

A section of 20km length on NH15 between Bikaner and Shri Ganganagar is considered for the simulation experiments. The existing carriage way width is 3.6m without any hard shoulder. The detailed road data is presented in Table 5.9. The traffic mainly consists of heavy moving vehicles which constitutes 40%. The cars, two wheelers and ADV constitutes 17%, 17%, 26% respectively. Different flow levels varying from 100 veh/h to 300 veh/h are considered for simulation experiments. The detailed traffic data considered for the simulation experiments is shown in Table 5.10. The road conditions are assumed same for different flow levels. The mean journey speeds for all vehicle types and for each vehicle type at different flow levels are calculated. Table 5.11 shows the mean journey speeds for different vehicles at different flow levels. The regression equations are developed with speed as a function of flow for each vehicle type. The detailed regression outputs are shown in table 5.12. Mean journey speeds are presented in Table 5.11.

The proposed road is 7.0m wide. The proposed road has the sight distances greater than the minimum stopping sight distance. The same traffic is simulated under wide road conditions. The condition of the road is assumed to be same for different flow levels. The details of the proposed road data is presented in Table 5.9. Speed flow relations are obtained for each vehicle type and for all vehicle types. The detailed regression outputs are presented in Table 5.13.

Table 5.9 Road Data for NH15

Type	Narrow road
1. Site	NH15 -(Bikaner to Shriganganagar) (30.00km to 50.00km)
2. Length of the road stretch	20 km.
3. Pavement width	3.6 m.
4. Shoulder width	nil (earthen shoulder)
5. Number of road blocks	180
6. Average rise plus fall	13.26265
7. Maximum radius of curvature	49.94(10000/r)
8. Speed limit	65 km/h

Type	Proposed wide road
1. Site	NH15 (Bikaner to Shriganganagar) (30.00km to 50.00km)
2. Length of the road stretch	20 km.
3. Pavement width	7.0 m.
4. Shoulder width	nil (earthen shoulder)
5. Number of road blocks	163
6. Average rise plus fall	10.8170
7. Maximum horizontal curvature	40.98(10000/r)
8. Speed limit	80 km/h

r is the radius of curve in metres.

'able 5.10 Traffic Data For NH15

'eak hourly low	No. of cars	No. of HMVs	No. of SMVs	No. of two wheelers
00	17	40	26	17
24	21	49	32	21
34	23	53	35	23
56	26	62	40	26
00	34	80	52	34
60	44	104	67	45
00	51	120	78	51

able 5.11 Journey Speeds (km/h) at Different Flow Levels for NH15 - Narrow Road

low evel	All vehicle types Mean speed	S.D	Car Mean speed	S.D	HMV Mean speed	S.D	SMV Mean speed	S.D	Two wheelers Mean speed	S.D
00	31.54	15.05	40.75	10.00	39.85	9.35	10.63	2.35	34.90	5.4
24	29.80	12.40	38.00	6.35	36.66	6.95	10.54	2.25	32.63	5.1
34	28.25	13.30	37.35	10.85	34.57	9.00	10.51	2.20	30.16	6.25
56	26.95	13.05	33.74	8.55	30.41	10.42	10.49	2.30	29.00	8.80
00	25.35	10.45	32.20	7.05	30.02	7.30	10.46	1.95	28.13	5.00
60	23.45	10.20	30.50	8.70	27.12	7.60	10.10	1.90	25.42	6.10
00	19.23	8.85	24.35	7.55	21.13	7.00	10.06	2.05	23.16	5.00

Journey Speeds (km/h) at Different Flow Levels for NH15 - Wide road

low evel	All vehicle types Mean speed	S.D	Car Mean speed	S.D	HMV Mean speed	S.D	SMV Mean speed	S.D	Two wheelers Mean speed	S.D
00	31.54	20.40	40.75	10.50	39.85	11.85	10.63	2.50	34.90	8.2
24	43.80	19.80	56.50	14.85	51.76	15.35	13.51	2.85	45.76	12.1
.34	39.05	19.70	52.50	14.90	48.49	15.40	13.42	2.80	41.73	12.3
.56	35.85	19.35	49.80	15.60	42.12	17.85	12.91	2.30	38.42	12.9
200	30.7	17.40	39.64	16.75	35.85	16.85	12.41	1.85	34.81	12.8
260	28.05	14.1	34.48	14.8	33.60	14.25	11.97	1.40	30.05	13.2
300	26.65	16.40	31.92	16.60	30.70	15.95	11.75	1.80	28.50	13.5

Table 5.12

Speed Flow Relations for Vehicle Types on NH15 for the Case of Narrow Road

Car		
$Speed_{car}$	=	47.1203 - 0.08539*Flow (55.605)
R squared	=	0.91750
Standard Error of Y estimate	=	2.2034
Standard Error of Coefficient	=	0.01145
HMV		
$Speed_{HMV}$	=	46.779 - 0.0772*Flow (39.9856)
R squared	=	0.88853
Standard Error of Y estimate	=	2.20113
Standard Error of Coefficient	=	0.0114
All Vehicle Types		
Speed	=	36.194 - 0.05640*Flow (42.636)
R squared	=	0.8950
Standard Error of Y estimate	=	1.6620
Standard Error of Coefficient	=	0.00863

()F Calculated Value

Table 5.13

Speed Flow Relations for Vehicle Types on NH15 for the Case of Wide Road

Car	
$Speed_{car}$	=70.4725 - 0.13582*Flow (103.400)
R squared	= 0.96276
Standard Error of Y estimate	= 2.29319
Standard Error of Coefficient	= 0.01336
HMV	
$Speed_{HMV}$	= 66.18334 - 0.1277*Flow (24.803)
R squared	= 0.86112
Standard Error of Y estimate	= 4.4039
Standard Error of Coefficient	= 0.02565
All Vehicle Types	
Speed	= 51.8974 - 0.09133*Flow (35.585)
R squared	= 0.8989
Standard Error of Y estimate	= 2.6286
Standard Error of Coefficient	= 0.015310

()F calculated value

Figure 5.6 shows the speed flow relations for car, HMV, and for all vehicle types under the existing and the proposed road conditions. From the Figure it can be seen that there is a steep decrease in the mean journey speeds under both the conditions. This can be mainly due to the presence of slow moving vehicles which constitutes 26% of the total traffic. Since in the presence of slow moving vehicles, the other vehicles have to slow down to perform flying and accelerating overtaking events. It can be seen from figure that even on wide road conditions the speeds are less. This is mainly due to the presence of slow moving vehicles. Hence it can be concluded that the presence of large percentage of slow moving vehicles hampers speed of fast moving vehicles heavily. But under low flow levels their effect is negligible.

5.3.2 Estimation of Road User Cost :

The speed flow relations as obtained above are used to determine the road users cost using HDM, taking congestion effect into consideration. It is assumed that road is maintained in same condition throughout the analysis period, with the surface roughness of the same value. As explained in section 5.2.1, the same composition of Ambassador car, Premier car and Jeep among car category and Tata truck, Beaver truck and bus among HMV category is assumed.

Simulation experiments are carried out with ADT of 1500 veh/day in the base year , gradually increasing to 4800 veh/day during the analysis period of 20 years i.e. the peak hour flow

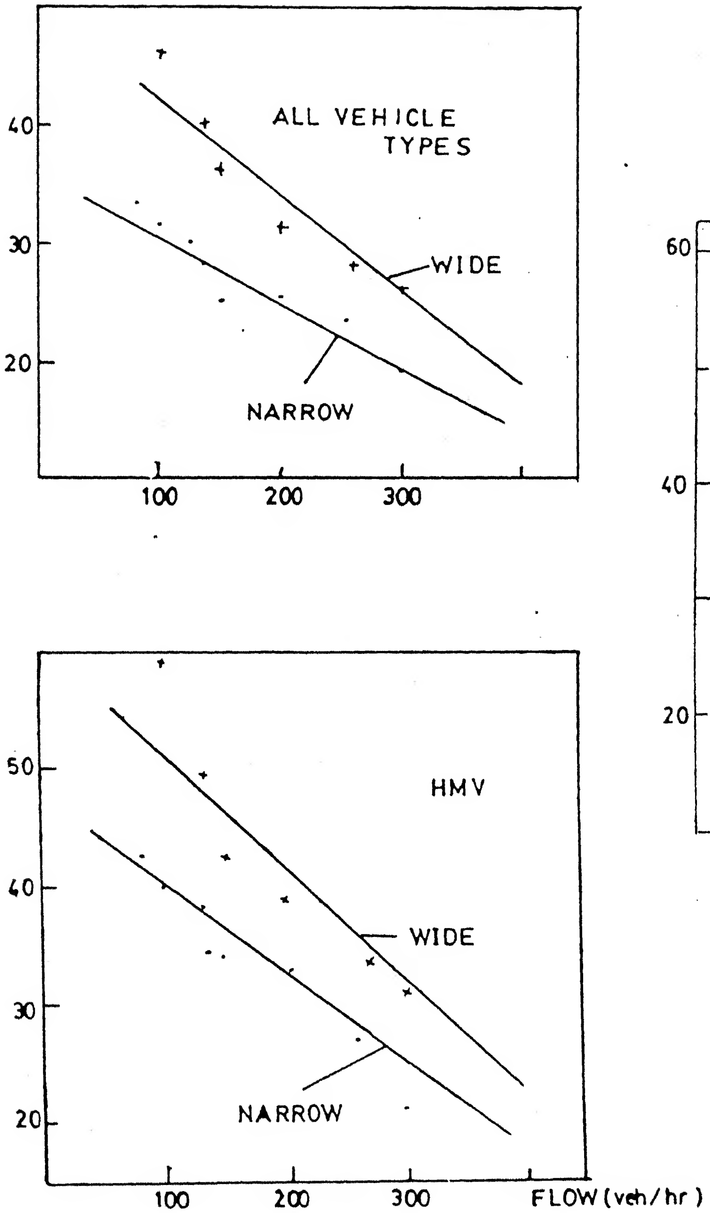


FIG 5·6 SPEED FLOW RELATIONS FOR NH15

varies from 100 veh/hr (approx.) to 320 veh/hr (approx.). The results obtained from the simulation runs are presented in Figures 5.7 to 5.10.

From figure 5.7 it can be seen that, under narrow and wide road conditions, the speeds are reducing. This may be due to the operating speed falling above the optimum operating speed under both the conditions. In the case of Tata truck, it can seen that under narrow road conditions it is increasing, this may be due to lower operating speeds. But in the case of wide road the variation is U shape, which may be due to the speeds are varying above and below the optimum operating speed. In the case of bus it can be seen that under narrow road conditions, the costs are increasing which may be attributed to the fact that operating speeds are left to the optimum speed. In the case of wide road it may be due to the operating speeds are right to that of optimum speed.

From Figure 5.8 it can be seen that the variation of total running cost assumes almost same pattern as the variation of the fuel cost in the case Ambassador and bus. But in the case of Tata truck the variation is different. The reason for this type of variation is same as explained in Section 5.2.1.

The total time cost increased under both the conditions as shown in the Figure 5.9, but the variation is high in the case of narrow road. The travel time cost is maintained at a constant value for Tata truck as explained in Section 5.2.1.

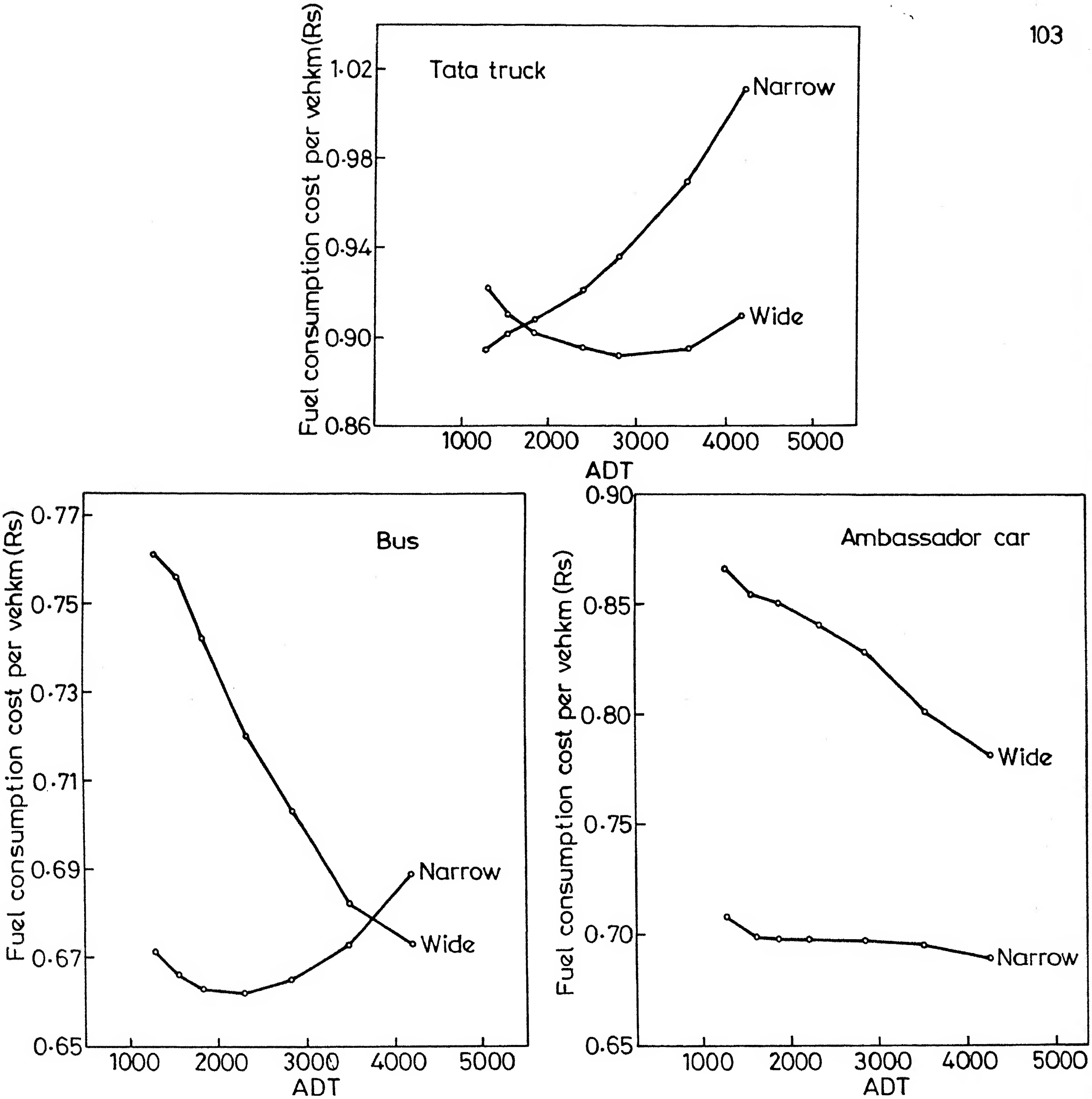


Fig.5·7 Fuel consumption cost per vehkm (Rs) vs ADT for NH15 under narrow and wide road conditions.

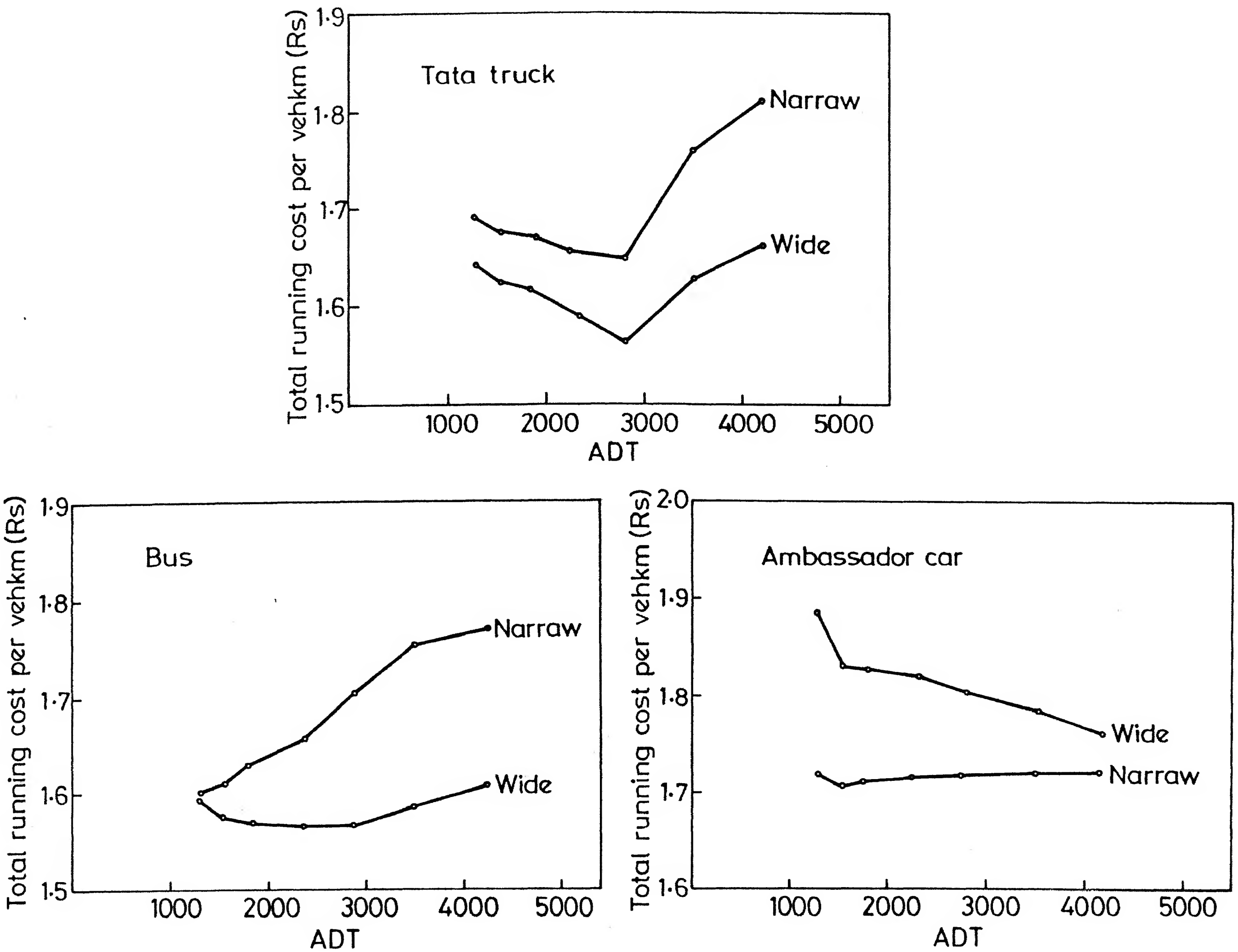


Fig. 5.8 Total running cost per vehkm (Rs) vs ADT for NH15 under narraw and wide road conditions.

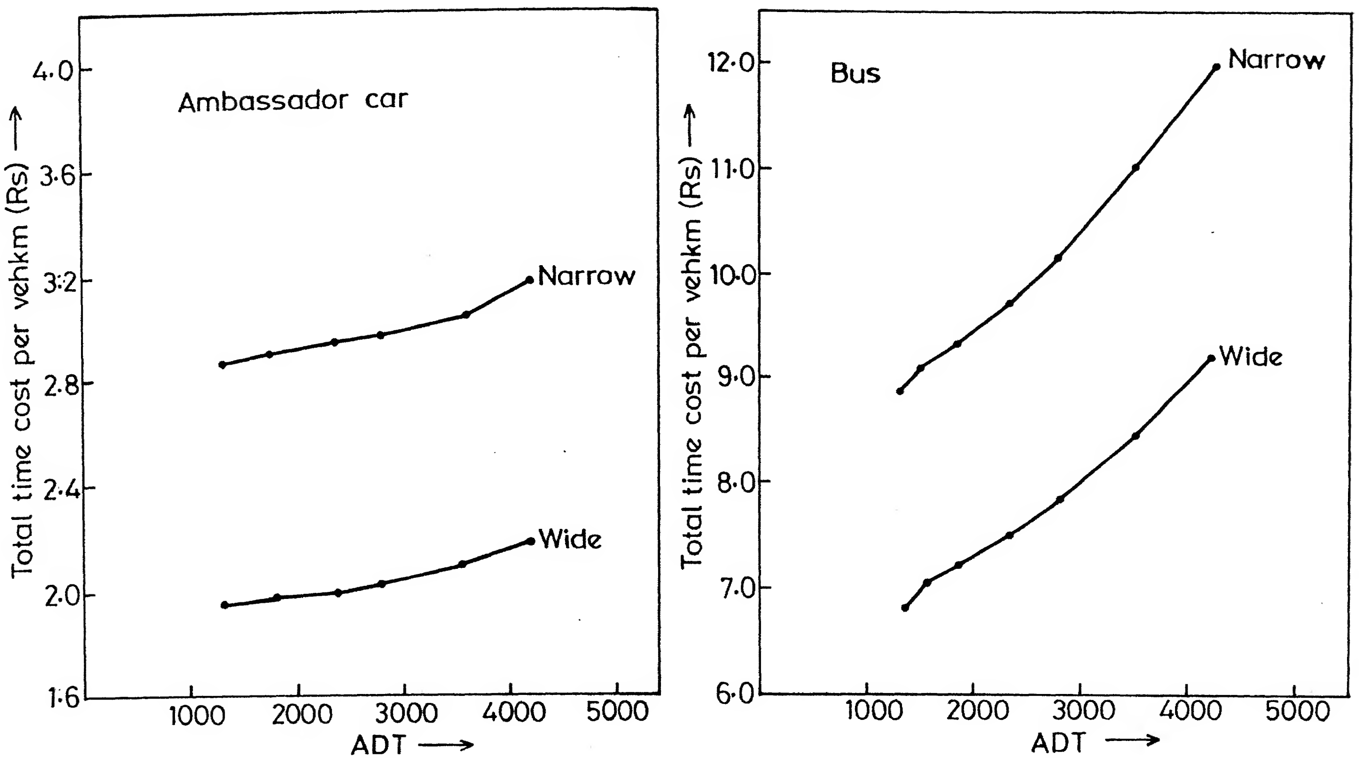


Fig.5.9 Total time cost per vehkm (Rs) vs ADT for NHIS under narrow and wide road conditions.

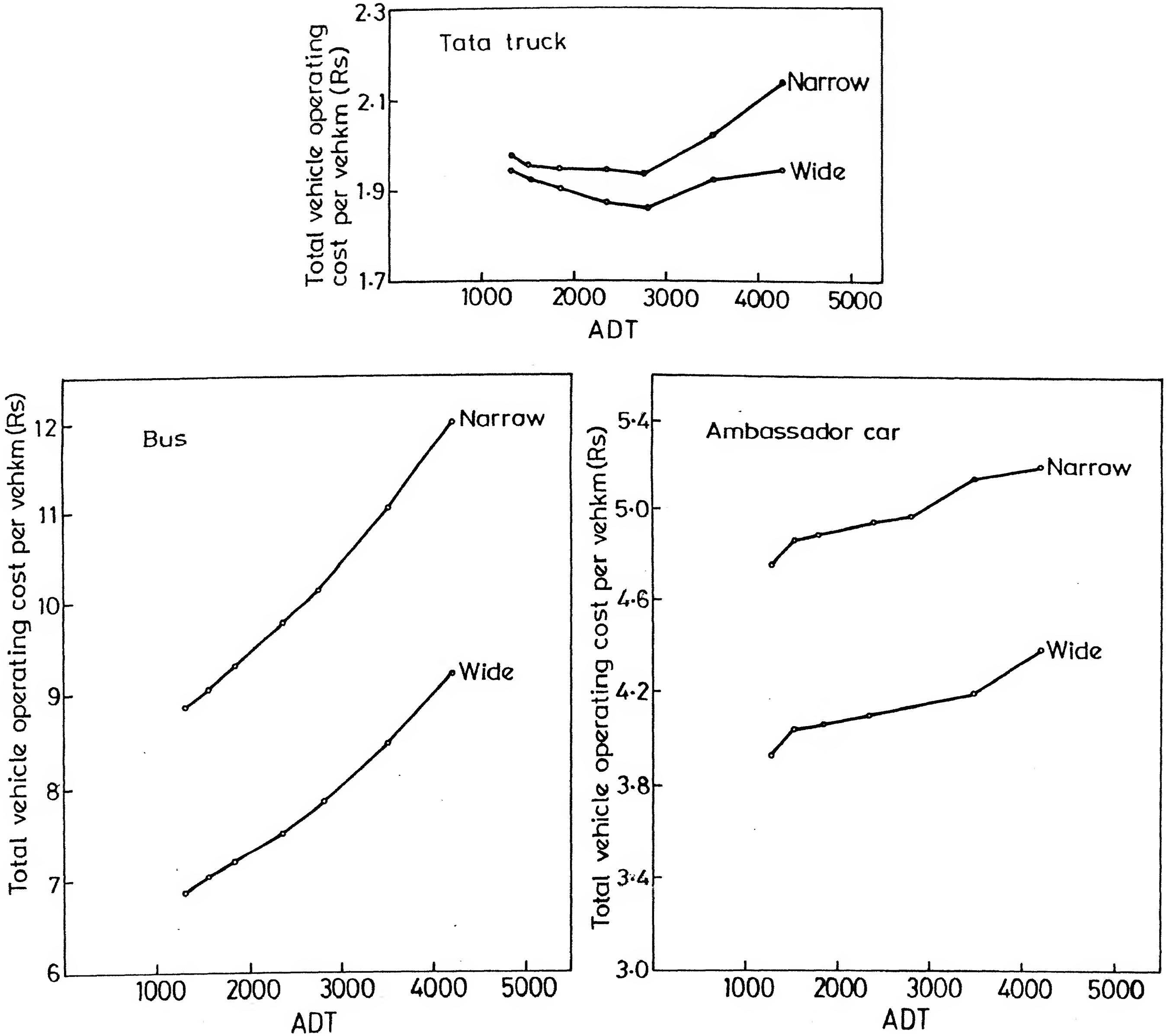


Fig. 5.10 Total operating cost per vehkm(Rs) vs ADT for NH15 under narrow and wide road conditions. 10

Figure 5.1Ø shows the total vehicle operating cost. It can be seen from this Figure that the total vehicle operating costs are increasing under both the conditions of roads for vehicle types Ambassador and bus, thus indicating the effect of travel time. In the case of truck the variation shows the similar trend as total running cost, since the time cost is constant.

5.4 Simulation Experiments on a Section of NH28 Road :

A section of 12 km length on NH28 between Gorakhpur and Bihar State border is considered for the simulation experiments. The existing carriageway width is 3.6m without any hard shoulder. The complete description of the road is presented in Table 5.14. The major composition of the traffic is heavy moving vehicles, which constitutes 68 percent. The slow moving vehicles and two wheelers constitute 2Ø percent of the total flow. Simulation experiments are carried out with the flaw levels varying from 15Øveh/hr. to 636veh/hr. The traffic data considered for the simulation experiments is presented in Table 5.15, the road condition are assumed same for different flow levels. The mean journey speed over the entire stretch is calculated for different flow levels and is tabulated in Table 5.16. The regression equation are developed for each vehicle type with speed as a function flow. The detailed regression outputs for each vehicle type are presented in Table 5.17.

The proposed road is 7.Øm wide. The traffic data as shown in Table 5.15 is considered for the simulation experiments. The road conditions are assumed same for different flow levels. The

Table 5.14 Road Data For NH28

Type	Narrow road
1. Site	NH28 - (Gorakhpur to Bihar border) (349.00km to 361.00km)
2. Length of the road stretch	12 km.
3. Pavement width	3.6 m.
4. Shoulder width	nil (earthen shoulder)
5. Number of road blocks	63
6. Average rise plus fall	0.7064
7. Maximum radius of curvature	20.00(10000/r)
8. Speed limit	65 km/h

Type	Proposed wide road
1. Site	NH28 - (Gorakhpur to Bihar border) (349.00km to 361.00km)
2. Length of the road stretch	12 km.
3. Pavement width	7.0 m.
4. Shoulder width	nil (earthen shoulder)
5. Number of road blocks	63
6. Average rise plus fall	0.60541
7. Maximum horizontal curvature	20.00 (10000/r)
8. Speed limit	80 km/h

r radius of curve in metres.

Table 5.15 Traffic Data For NH28

Peak hourly flow	No. of cars	No. of HMVs	No. of SMVs	No. of two wheelers
150	30	102	7	11
308	59	210	15	24
445	84	302	25	34
636	120	433	34	49

Table 5.16 Journey Speeds (km/h) at Different Flow Levels for NH28 - Narrow Road

Flow level	All Vehicle types Mean speed	S.D	Car Mean speed	S.D	HMV Mean speed	S.D	SMV Mean speed	S.D	Two wheelers Mean speed	S.D
150	38.35	9.95	41.37	6.25	39.74	6.75	10.75	2.35	34.90	6.9
308	31.35	7.90	33.25	6.55	31.55	5.20	10.30	1.65	31.55	6.7
445	20.10	9.70	19.78	10.00	24.94	1.90	9.25	1.70	21.80	7.0
636	15.15	7.70	16.11	8.00	16.11	7.45	7.40	2.40	16.55	7.4

Journey Speeds (km/h) at Different Flow Levels for NH28 - Wide Road

Flow level	All Vehicle types Mean speed	S.D	Car Mean speed	S.D	HMV Mean speed	S.D	SMV Mean speed	S.D	Two wheelers Mean speed	S.D
150	50.00	16.64	53.87	16.25	53.41	12.20	14.70	3.20	43.50	14.4
308	36.15	19.20	38.05	20.15	37.93	18.20	13.90	2.05	36.40	15.9
445	31.15	16.35	30.65	16.00	31.50	17.65	13.18	2.65	34.16	14.5
636	25.90	15.45	23.69	15.80	25.99	15.35	12.95	2.50	30.29	16.4

Table 5.17

Speed Flow Relations for Vehicle Types on NH28
for the case of Narrow Road

Car	
$Speed_{car}$	= 49.798 - 0.05499*Flow (27.612)
R squared	= 0.93246
Standard Error of Y estimate	= 3.7422
Standard Error of Coefficient	= 0.01046
HMV	
$Speed_{HMV}$	= 48.678 - 0.0555*Flow (42.359)
R squared	= 0.95491
Standard Error of Y estimate	= 3.05096
Standard Error of Coefficient	= 0.00853
All Vehicle Types	
Speed	= 45.498 - 0.05002*Flow (47.78)
R squared	= 0.9598
Standard Error of Y estimate	= 2.588
Standard Error of Coefficient	= 0.00723

() F calculated value

details of the proposed road is presented in Table 5.14. Mean journey speed over the stretch is calculated for different flow levels and speed flow relations are obtained using linear regression. Details of the mean journey speeds are presented in Table 5.16. Details of the regression outputs are presented in Table 5.18.

Figure 5.11 shows flow relations for car, HMV and for all vehicle types under the existing and proposed road conditions. From this Figure it can be seen that the mean journey speed reduces with flow under both the conditions. But the slope of the speed flow curve is less than the slope of the curve for NH 15. From that it can be concluded that, the presence of slow moving vehicles affects the mean journey speed heavily.

5.4.1 Estimation of Road User Cost :

The speed flow relations are used to determine the road user cost. As explained in the previous section it is assumed that the road is maintained in same condition throughout the analysis period. Simulation experiments are carried out with ADT of 2250 veh/day in the base year, gradually increasing to 13250 veh/day during the analysis period of 17 years, i.e. the peak hour flow varies from 150 veh/hr (approx.) to 890 veh/hr (approx.). The results obtained from the simulation runs are presented in Figures 5.12 to 5.15.

From Figure 5.12 it can concluded that, under narrow and wide road conditions, the variations are in U shape for Ambassador car and truck. This can be due to the speeds are

Table 5.18

Speed Flow Relations for Vehicle Types on NH28
for the Case of Wide Road

Car	
$Speed_{car}$	= 59.75134 - 0.28167*Flow (16.962)
R squared	= 0.89453
Standard Error of Y estimate	= 4.78556
Standard Error of Coefficient	= 0.01338
HMV	
$Speed_{HMV}$	= 58.3638 - 0.05495*Flow (21.872)
R squared	= 0.91662
Standard Error of Y estimate	= 4.20171
Standard Error of Coefficient	= 0.01175
All Vehicle Types	
Speed	= 54.2634 - 0.04795*Flow (21.545)
R squared	= 0.915054
Standard Error of Y estimate	= 3.694662
Standard Error of Coefficient	= 0.010331

() F calculated value

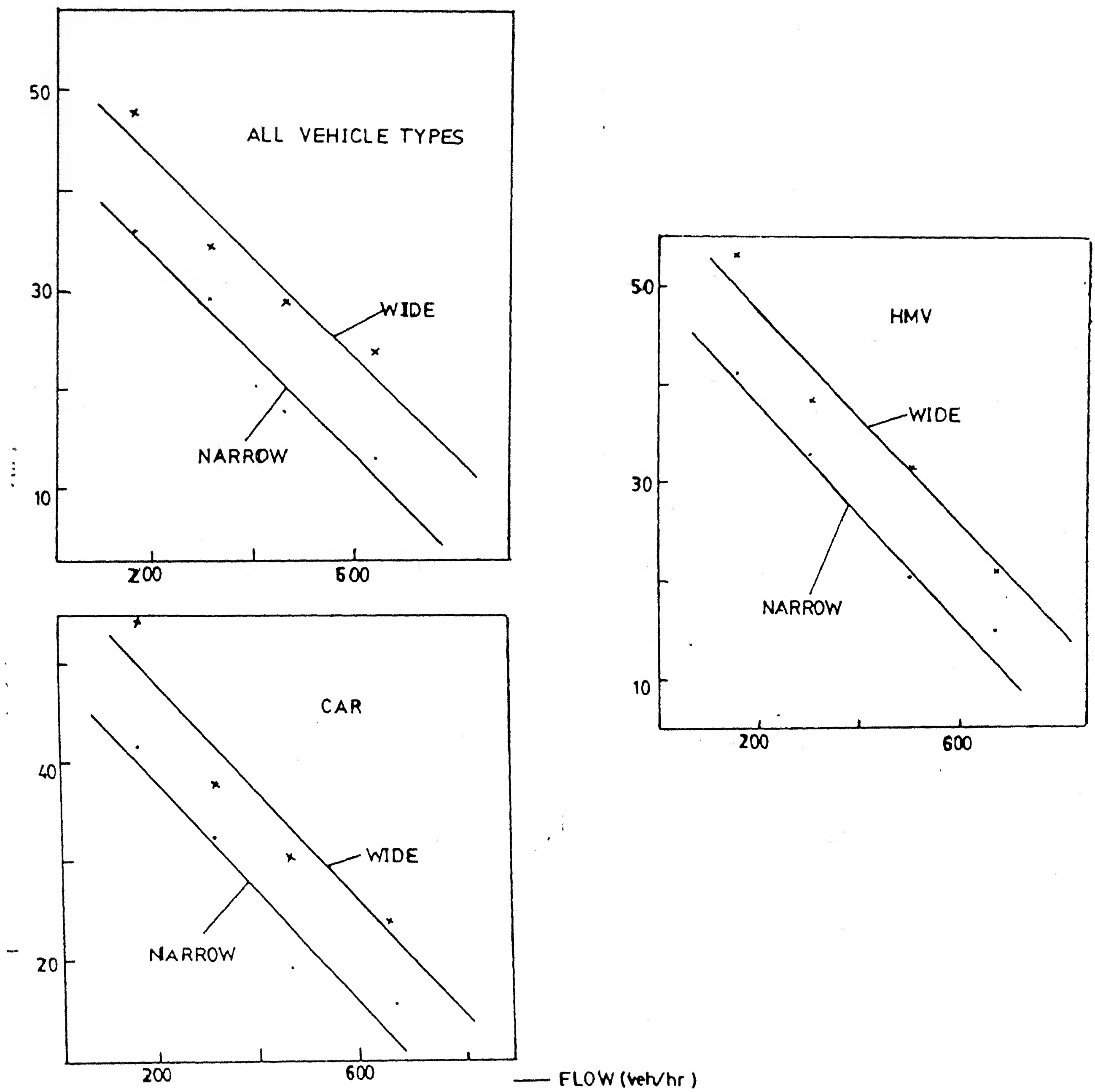


FIG. 5.11 SPEED FLOW RELATIONS FOR NH28

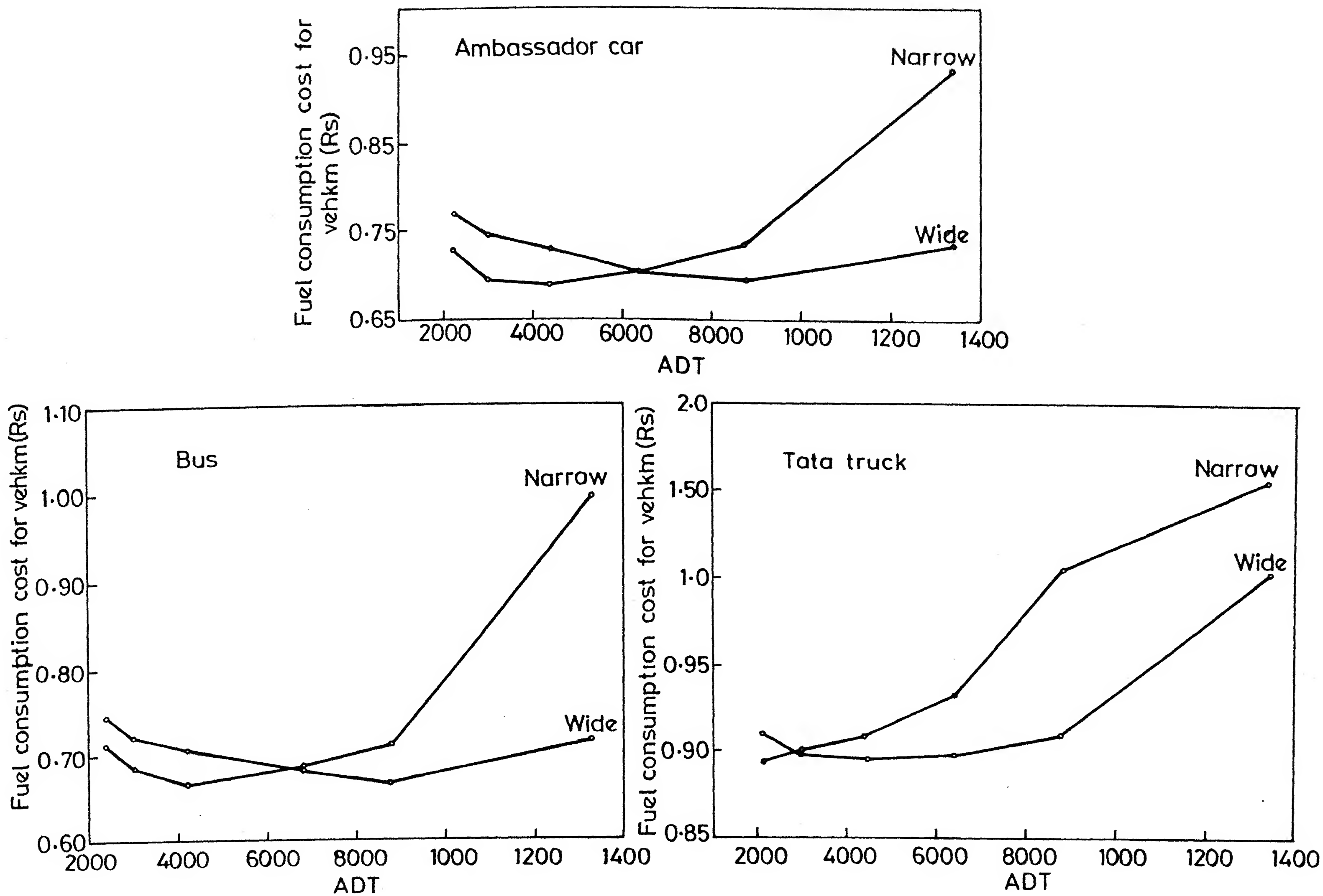


Fig. 5.12 Fuel consumption cost per vehkm (Rs) vs ADT for NH28 under narrow and wide road conditions.

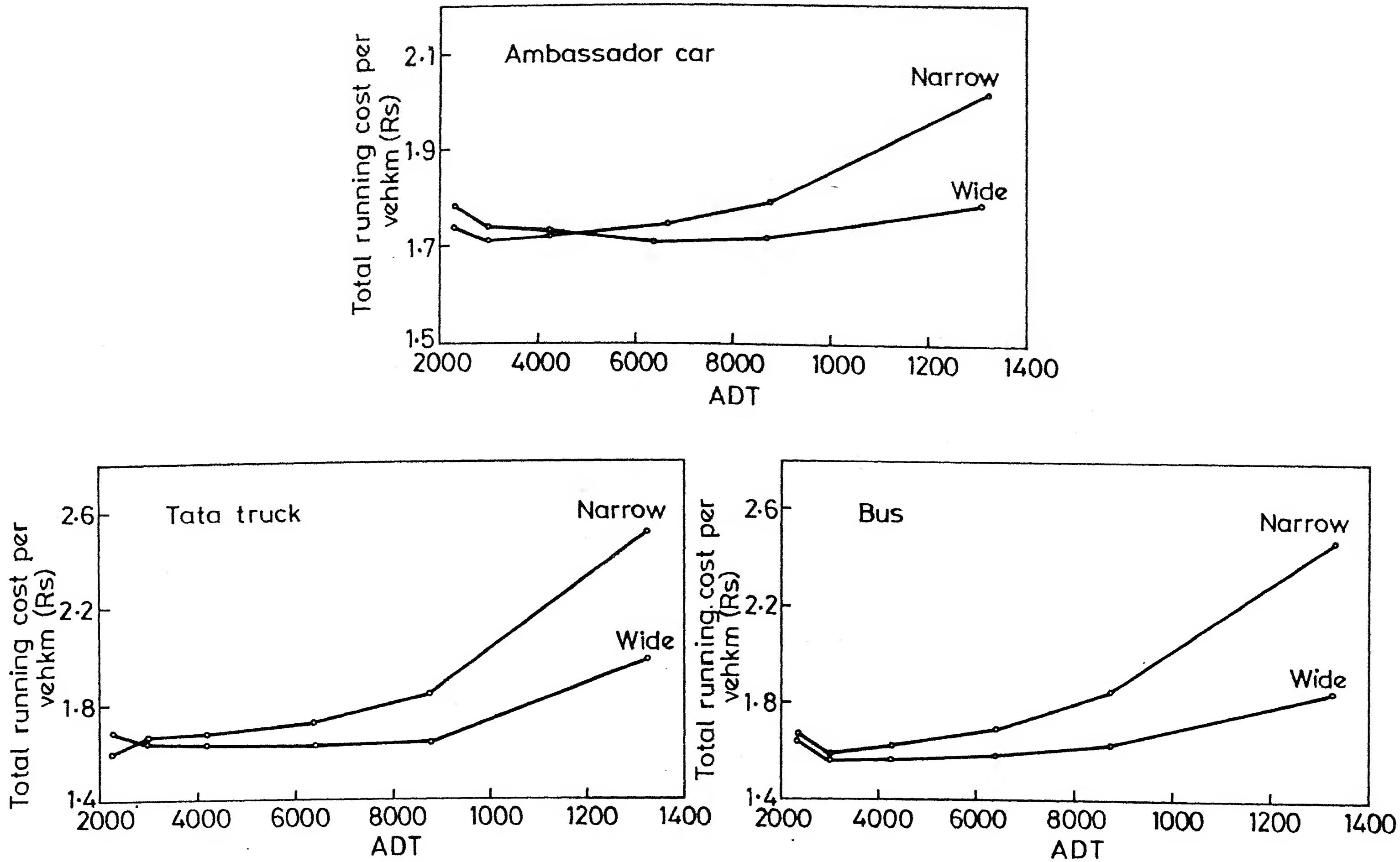
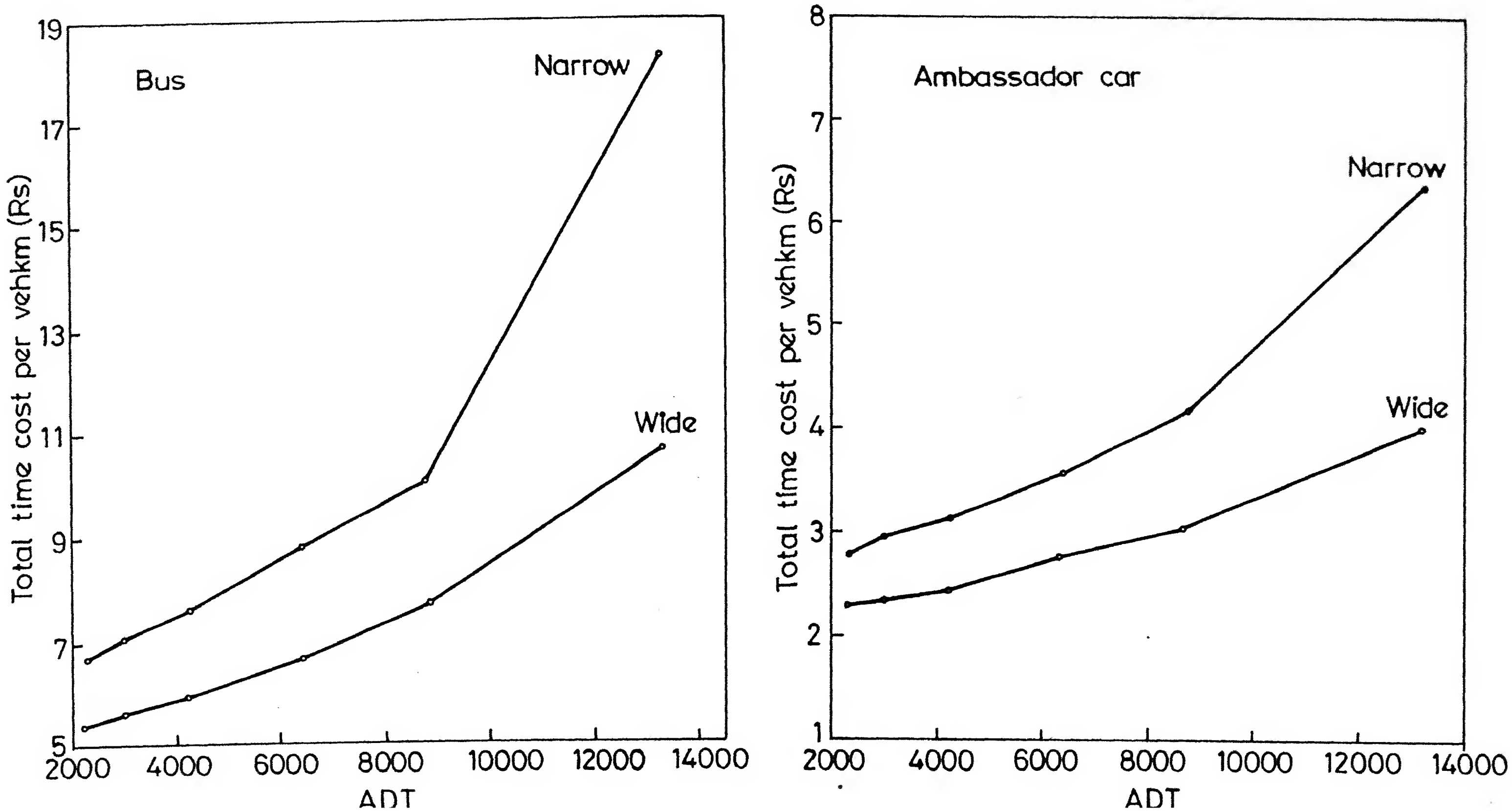


Fig. 5·13 Total running cost per vehkm (Rs) vs ADT for NH28 under narrow and wide road conditions.



Bus
Narrow
Wide
Total time cost per vehkm (Rs)
19
17
15
13
11
9
7
5
2000
4000
6000
8000
10000
12000
14000
ADT
Ambassador car
Narrow
Wide
Total time cost per vehkm (Rs)
8
7
6
5
4
3
2
1
2000
4000
6000
8000
10000
12000
14000
ADT

:ions.

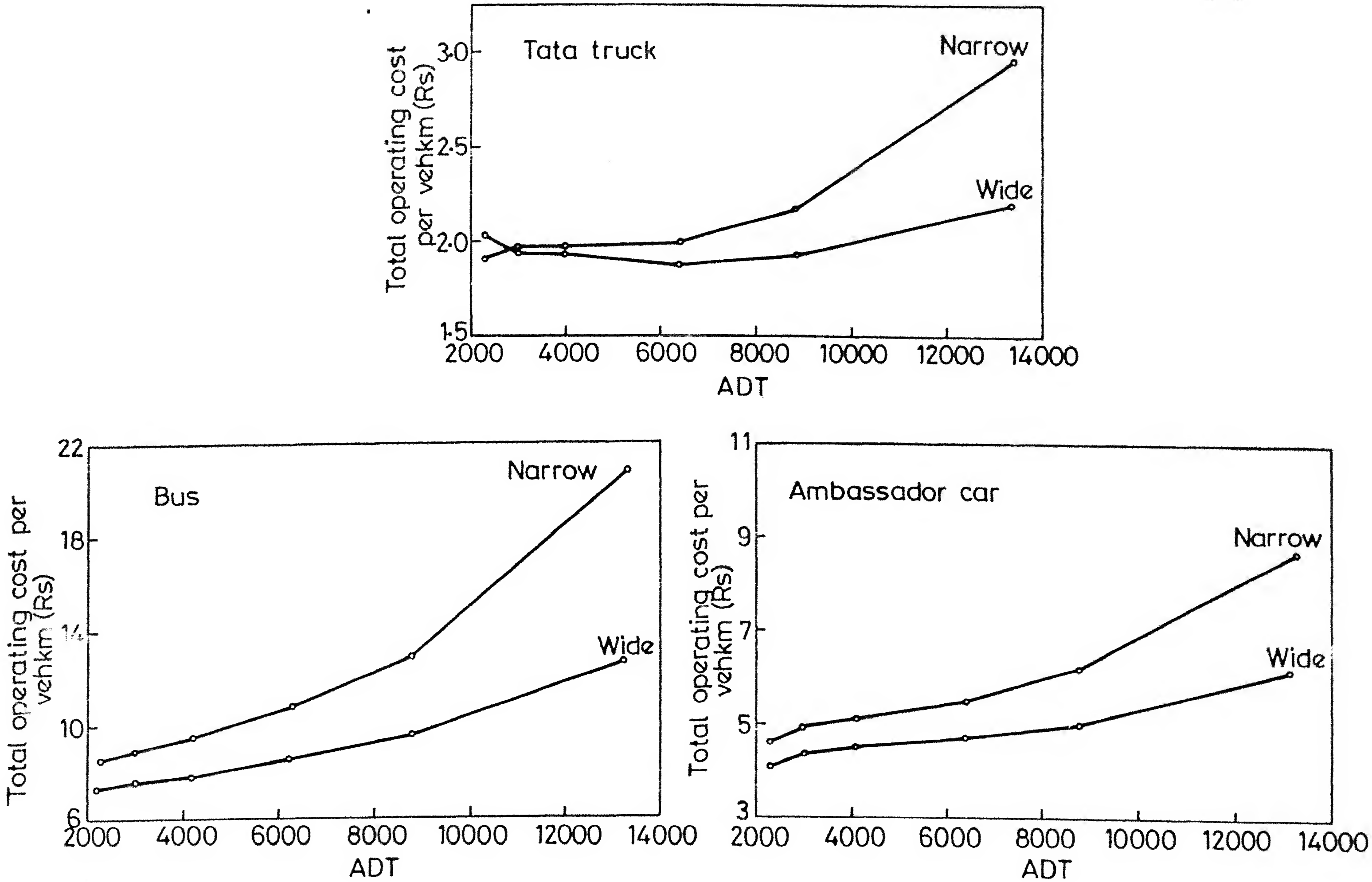


Fig. 5.15 Total vehicle operating cost per vehkm (Rs) vs ADT for NH28 under narrow and wide road conditions.

falling just to the left of optimum speed in the case of narrow roads and in the case of wide roads the speeds are just to the right of optimum speed. In the case of trucks it can be due to the right of optimum speed speed in the case of wide roads and left of optimum speed in the case of narrow roads.

From Figure 5.13 it can be seen that the total running cost almost follows the same pattern as the fuel cost in the case of Ambassador car and bus. In the case of Tata truck the reason for the variation may be same as explained in Section 5.2.1.

The total time cost increases for both Ambassador car and bus as shown in the Figure 5.14. The variation is very high in the case of narrow roads which is naturally due to low operating speeds. The travel time cost is maintained at a constant value for Tata truck as explained in Section 5.2.1.

Figure 5.15 shows the total vehicle operating cost. In the case of Tata truck, it can be seen that the variation follows the similar trend as total running cost. In the case of Ambassador car and bus the total vehicle operating cost increases as ADT increases. The rate of increase is high in narrow roads, which quite natural.

Various roads considered for the simulation experiments, speed flow relations for each road under the existing and proposed road conditions have been presented in this Chapter. The detailed evaluation of the road user cost for each road under both conditions was also presented in this Chapter. For each case

the results obtained were discussed. Next Chapter presents the summary of the present work, conclusions and scope for the further work.

CHAPTER VI

SUMMARY, CONCLUSIONS AND SCOPE FOR FURTHER WORK

6.1 Summary:

The primary objective of the present thesis is to evaluate the speed flow relations and the road user cost for different roads under the existing and proposed road conditions. The road user costs are to be evaluated by taking congestion effect into consideration. Finally to modify the existing traffic simulation and other connected models to capture the highly heterogeneous nature of the Indian road traffic.

Three different roads are considered which vary widely in their traffic composition and road conditions. One of these stretches is a hilly terrain on NH7 between Nagpur and Hyderabad. The stretch is having steep slopes and hairpin bends. The traffic is mainly composed of cars, heavy motor vehicles (HMV)and two wheelers with 15%, 73% and 13% respectively. The second stretch is a highway in plain terrain on NH15 between Bikaner and Shriganganagar. The traffic contains considerable percentage of slow moving vehicles. The traffic composition for car, HMV, animal drawn vehicle (ADV) and two wheelers are 17%, 40%, 26%, 17% respectively. The third stretch is also on a plain terrain on NH28 between Gorakhpur and Bihar State border. Traffic on this road constitutes 68% HMV, 20% car, 5% ADV and 7% two wheelers. All these stretches are presently 3.6m wide. These stretches are simulated for the existing traffic and for the future growth of

the traffic. These road stretches are also simulated for the proposed 7.0m wide road conditions. Speed flow relations were obtained for these stretches under both the conditions. These speed flow relations have been used to evaluate the road user cost taking the congestion effect into consideration.

The existing simulation model considers 4 vehicle types. These are car, HMV, ADV and two wheelers. The present traffic contains many vehicle types varying from Maruti car to bullock cart. Even among car category many types of cars which vary widely in their basic desired speed (BDS) and power to mass ratio (P/m) are exist. The same is the case with HMV and two wheelers. The simulation model considers the road stretch as a series of homogeneous blocks. For each block it considers the block median speed and transformation measure (Q value) irrespective of the vehicle type to determine the freeblock speed. Hence the simulation model and other connected models were modified to reflect the Indian traffic system. The proposed modifications to the simulation model can be summarized as follows: 20 different vehicle types which vary widely in their BDS and P/m distributions are considered to reflect the heterogeneous nature of the traffic. The road submodel is modified to calculate the block median speed and Q value for each vehicle type by considering effect of road width, radius of curve, and speed limit for each vehicle type separately. The constants related with the measure of effect of roadwidth and horizontal curve for each vehicle type are evaluated intuitively by experimenting with Lotus 1-2-3. The traffic submodel i.e. the standard traffic

generation program is modified to generate 20 vehicle types. The BDS distribution and P/m distributions for each vehicle type are not available readily. These distributions are assumed accordingly with the help of the available data. Comparisons has been made between the generated and the assumed distributions of BDS and P/m ratio for each vehicle type. The calculation procedure of freeblock speed and freecross speed is modified by considering the block median speed and Q value separately for each vehicle type in the main simulation program. The overtaking procedure in the main simulation program is simplified by dividing the 20 vehicle types into 6 categories to calculate the overtaking probabilities.

6.2 Conclusions:

From the modified simulation model we can evaluate the journey speeds, time headways and spot speeds separately for each vehicle type. The results were shown a clear trend of decrease in the mean journey speeds as flow increases. From the results it can be seen that speeds are much high in the case of narrow roads compared to the wide roads. It is also observed that the vehicle types like Maruti car has higher journey speeds compared to temp. Hence it can be concluded that the results are consistent with respect to assumed distributions.

From the speed flow relation for different roads it can be seen that , if the existing conditions are continued, the operating speeds reduce much faster. From the speed flow relations it can be seen that the presence of slow moving

vehicles reduces the speeds considerably. It can be concluded that the reduction in speeds is much higher in the presence of considerable percentage of slow moving vehicles.

Fuel consumption cost, total running cost, total time cost and total vehicle operating costs were evaluated per vehicle km for each road stretch under the present and the proposed road conditions. These costs were evaluated by using the procedure (RECST) incorporated in the Highway Design and Maintenance Model by Chalpathi(1987). The costs are evaluated by dividing the average daily traffic (ADT) into hourly traffic and by determining the speed for each hour from the speed flow relations. The results of the experiments shows the effect of travel time savings in the case of wide roads. The travel time cost is assumed constant with fixed cargo for Tata truck. Hence it has shown a trend different from that of Ambassador car and bus.

6.3 Scope for Further Work:

Peak hour flow is considered for the simulation experiments. The ADT is calculated from the peak hour flow based on the study conducted by Maharashtra Engineering Research Institute. The simulation experiments can be carried out for ADT and speed flow relations can be obtained from these experiments. From these speed flow relations road user costs can be evaluated. The HDM as presented here calculates the speeds from the speed flow relations and evaluates the road user cost. The effect of traffic congestion such as frequent speed change cycles resulting in

increased fuel cost, tire wear, cost of spare parts etc. are not reflected in the vehicle operating cost relationships. Thus, further empirical research is necessary to quantify these costs by developing the appropriate relationships.

All the constants and distributions were assumed for 20 vehicle types in the case of modified simulation model. The model can be made versatile by evaluating the constants and speed distributions separately for each vehicle type from the field data. The following are some of the possible applications of the modified simulation model.

1. By changing the traffic composition the effect can be studied.

2. The effect of large percentage of Maruti cars and other light motor vehicles in the traffic streams can be studied.

3. The effect of large percentage of slow moving vehicles such as bullock carts and horse carts in the traffic streams can also be studied.

4. By changing the traffic characteristics with an entirely new traffic composition the effects can be studied.

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